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p COLUMBIA UNIVERSITY

DEPARTMENT OF PHYSICS

■ TWELFTH QUARTERLY PROGRESS REPORT

SEPTEMBER 16, 1962 THROUGH DECEMBER 15, 1962

COLUMBIA RADIATION LABORATORY NEW YORK 27, NEW YORK

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Columbia Radiation Laboratory, Columbia University
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Twelfth Report on RESEARCH INVESTIGATION DIRECTED TOWARD EXTENDING
THE USEFUL RANGE OF THE ELECTROMAGNETIC SPECTRUM

Report dated: December 15, 1962
viii + 64 pages, 13 figures

Evidence has been found for the existence of the $(1s\,2s\,2p)^4P_{5/2}$ metastable state of the lithium atom. This state decays by autoionization with a lifetime of about 10 μsec. In addition to its intrinsic interest, this state and similar states in other atoms warrant study because they may serve as useful sources of polarized electrons and ions. Final results are reported on the magnetic moment of O15. Precise values for the zero field hyperfine intervals and the level crossing fields of 245 day Zn^{65} are reported. The spin, magnetic moment, and quadrupole moment of 43 day Cd115m have been determined by optical double resonance. Theoretical calculations of the moments of the cadmium and zinc isotopes have been made on the basis of the configuration mixing model; these are compared with the experimental values.

New precise values of the HDS molecular parameters have been deduced from the measurements reported previously. Initial results are reported on the optical maser spectroscopy program.

In the cooperative radioastronomy program with the Naval Research Laboratory, it has been found that the 3200 Mc/sec radiation from Saturn is linearly polarized and that the magnetic poles of Saturn appear to be located in the equatorial plane of the planet.

COLUMBIA RADIATION LABORATORY

RESEARCH INVESTIGATION DIRECTED TOWARD
EXTENDING THE USEFUL RANGE OF THE
ELECTROMAGNETIC SPECTRUM

Twelfth Quarterly Progress Report
September 16, 1962 through December 15, 1962
CU-12-62 SC-78330 and SC-90789 Physics

This report covers the last one and one-half months of Contract DA 36-039 SC-78330 and the first one and one-half months of successor Contract DA 36-039 SC-90789.

Object of the research:
Physical research in fields in which microwave frequency techniques are employed; the development of microwave electronic and circuit devices.

DA Task No. 3A99-20-001-09
NR 372-101

Prepared by R. Novick

COLUMBIA UNIVERSITY
Division of Government Aided Research
New York 27, N. Y.

December 15, 1962

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A. G. Anderson (IBM Research Laboratory, San Jose, Calif.) and S. R. Hartmann* (University of California, Berkeley, Calif.), "Nuclear magnetic resonance in the demagnetized state," Phys. Rev. 128, 2023 (1962).

S. R. Hartmann* and E. L. Hahn (University of California, Berkeley, Calif.), "Nuclear double resonance in the rotating frame," Phys. Rev. 128, 2042 (1962).

H. Leupold, "Superconducting and normal specific heats of niobium," Phys. Rev. 127, 1501 (1962).

L. Wharton, L. P. Gold,* and W. Klemperer (Harvard University, Cambridge, Mass.), "Preliminary values of some molecular constants of lithium hydride," J. Chem. Physics 37, 2149 (1962).

Papers by CRL Staff Members Presented at Scientific Meetings

American Physical Society, 1962 Thanksgiving Meeting, Case Institute of Technology and Western Reserve University, Cleveland, Ohio, November 23-24, 1962

I. D. Abella and C. H. Townes,[†] "Optical double-photon absorption in cesium vapor," Bull. Am. Phys. Soc. 7, 554 (1962).

A. Landman and M. N. McDermott,[‡] "Optical detection of level crossings in Zn^{65}," ibid., 533.

M. N. McDermott,[‡] R. Novick, B. Perry, "Nuclear spin and moments of Cd^{115m}," ibid.

M. N. McDermott,[‡] R. Novick, B. Perry, "Nuclear spin and moments of 245 day Zn^{65}," ibid.

Meeting on the Physics of Non-thermal Radio Sources, Institute of Space Studies, New York, N. Y., December 3, 1962

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H. Bucka,** "Determination of nuclear quadrupole moments by optical double resonance," Resonance Seminar, Department of Physics, Columbia University, October 19, 1962.

B. Budick, "Atomic beam studies of radioactive rare earths," Resonance Seminar, Department of Physics, Columbia University, November 2, 1962.

L. P. Gold, "Electric resonance microwave spectrum and spectroscopic constants of lithium fluoride," Resonance Seminar, Department of Physics, Columbia University, November 16, 1962.

S. R. Hartmann, "Nuclear magnetic resonance in a demagnetized state," Colloquium, Department of Physics, Columbia University, November 9, 1962.

A. Lurio,†† "Level crossing spectroscopy," Colloquium, Johns Hopkins University, November 15, 1962.

ABSTRACT

Evidence has been found for the existence of the $(1s\,2s\,2p)^4P_{5/2}$ metastable state of the lithium atom. This state decays by autoionization with a lifetime of about 10 μsec. In addition to its intrinsic interest, this state and similar states in other atoms warrant study because they may serve as useful sources of polarized electrons and ions. Final results are reported on the magnetic moment of O^{15}. Precise values for the zero field hyperfine intervals and the level crossing fields of 245 day Zn^{65} are reported. The spin, magnetic moment, and quadrupole moment of 43 day Cd^{115m} have been determined by optical double resonance. Theoretical calculations of the moments of the cadmium and zinc isotopes have been made on the basis of the configuration mixing model; these are compared with the experimental values.

New precise values of the HDS molecular parameters have been deduced from the measurements reported previously. Initial results are reported on the optical maser spectroscopy program.

In the cooperative radioastronomy program with the Naval Research Laboratory, it has been found that the 3200 Mc/sec radiation from Saturn is linearly polarized and that the magnetic poles of Saturn appear to be located in the equatorial plane of the planet.

FIGURE 1. Beam intensity at station No. 8 as a function of axial magnetic field: a) optimized at high field; b) reoptimized at a selected lower field. Vertical scale is beam intensity 1.2×10^{-9} A/box; horizontal scale is axial magnetic field 9.2 G/box.

(a)

(b)

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I. ATOMIC PHYSICS

A. LIFETIME OF THE METASTABLE STATE OF SINGLY IONIZED HELIUM*
(M. Lipeles, R. Novick)

This is an experiment to measure the lifetime of the 2S metastable state of singly ionized helium by a time-of-flight method.

The apparatus consists of a 34-ft long, stainless steel, bakeable vacuum tube. The tube is divided into four separately pumped chambers by baffle plates with small diameter apertures through which the ion beam may pass. The first chamber contains the ion source through which helium gas is passed at a pressure of 2×10^{-5} Torr (air equivalent) and bombarded by 450 volt electrons to give a 1×10^{-8} A beam of helium ions of which about 1% are in the metastable state. The first intermediate chamber, primarily for vacuum separation, contains a microwave quenching cavity for modulating the metastable component of the beam and operates at a pressure of 5×10^{-7} Torr (air equivalent). The third chamber also serves as a vacuum separation chamber and operates at about 5×10^{-8} Torr (air equivalent). The fourth chamber is a 30-ft long drift tube containing a movable detector and operates at a pressure of 5×10^{-9} Torr (air equivalent). The beam is constrained to move down the axis of the drift chamber by an axial magnetic field which is started abruptly at the beginning of the drift chamber by a large Armco plate. A surface Auger detector is moved along the length of the 30-ft chamber and is contacted at twelve fixed points. The lifetime is determined by observing the decrease in the modulated metastable signal as a function of distance.

We have continued our measurements of beam intensity as a function of the axial magnetic field and have found that under some focusing conditions considerable scalloping of the beam occurs. Since the "trombone" current control for this field is inconvenient and difficult to adjust, it has been replaced by a transistor control circuit which employs twenty 2N2152 transistors in parallel to achieve continuous variation of storage battery supplied current from 0 to 400 A. Fig. 1(a) shows an example of the results obtained by optimizing the beam intensity with the axial magnetic field near its maximum value. With the same magnetic field range but with better conditions on the electrostatic lenses, the results shown in Fig. 1(b) were obtained.
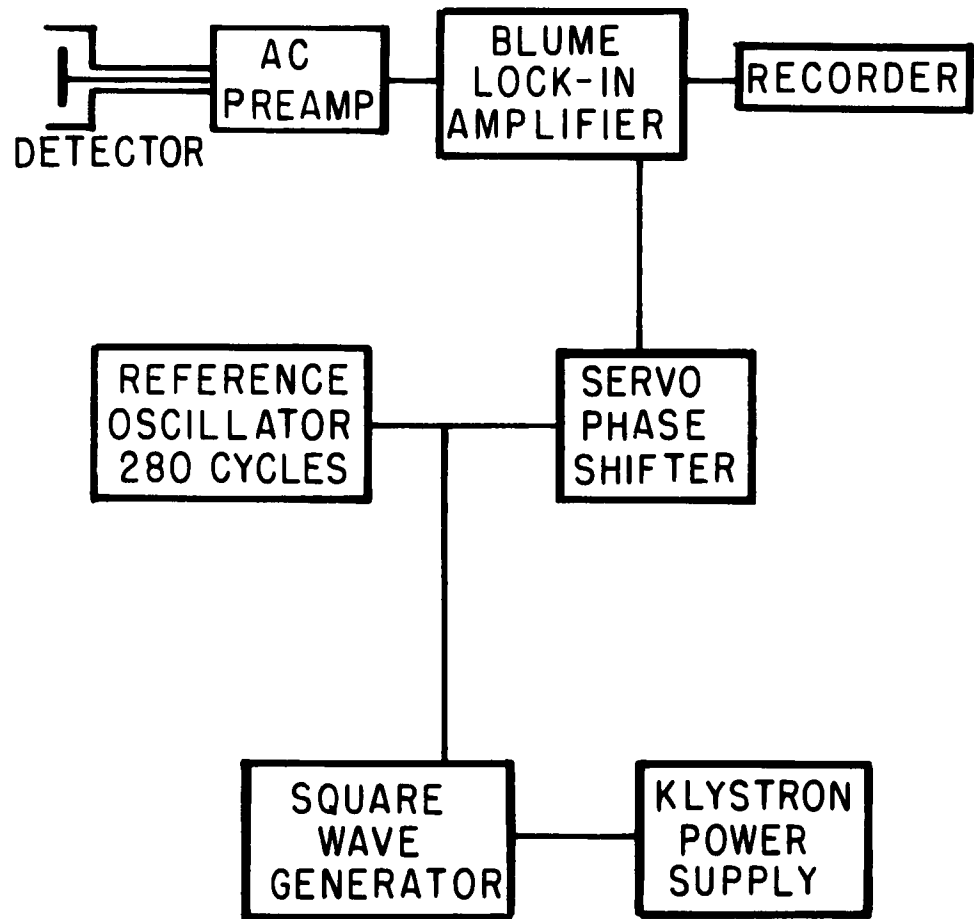
FIGURE 2. New detection electronics.

The procedure for obtaining these results is neither straightforward nor consistently successful. Thus, although similar plateaus can be reached at all stations simultaneously and under the same conditions, we are not convinced that the beam is really confined within a certain diameter over its entire course. Consequently, a sliding connection for the detector has been designed which will allow continuous reading of the ground state beam over the entire 30-ft drift tube.

A new ac detection scheme for the metastable signal which employs narrow banding and lock-in detection is in the process of being constructed. As shown in Fig. 2, the phase of the reference signal to the lock-in circuit varies continuously as a function of time with some predetermined period. The output of the lock-in circuit is then fed to a recorder on which the peak-to-peak value of the resulting sine wave is taken as the metastable signal.

Preliminary results with this detector are not self consistent and vary from day to day. This appears to be due to instabilities in the source and/or the focusing of the beam which introduce nonrandom noise. The effects of electrons in the beam are being studied in an approximate fashion by replacing the helium with argon for which the metastable signal should not be present. The first trial run with argon showed no metastable signal above the noise. However, the experiment was not conducted with the improved electronics described above, so there was considerable noise. Thus far, we have not obtained sufficient data in a single run to provide a lifetime determination.

Program for the next interval: During the next quarter we will 1) install the continuous detector for the ground state beam, 2) continue to improve the signal-to-noise ratio, the self consistency of the metastable signal and its relation to the ground state signal, and 3) continue lifetime measurements.

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B. OPTICAL DETECTION OF LEVEL CROSSINGS

1. Optical Detection of Level Crossings in the $(4s\,4p)^3P_1$ State of Zn^{67}
    (A. Landman, R. Novick)

The computer program to incorporate the second order fine struc-
ture corrections in the determination of A, B, and g_J from the four experi-
mentally obtained level crossings has not proven wholly satisfactory. A
simpler and more direct approach has now been undertaken which involves
hand fitting, or essentially a trial-and-error method to fit the four experi-
mental numbers by varying the values of A, B, and g_J.

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2. Optical Detection of Level Crossings in the $^2P_{3/2}$ States of Na^{23} and Rb^{87}*
    (R. J. Goshen, P. Thaddeus,[†] R. de Zafra)

The beam-type apparatus mentioned in the last report has been
completed and a trial run conducted with Li^7. Despite several modifica-
tions of the oven design, we were unable to obtain a sufficient density of
Li atoms in the beam.

No new cells were made during the last quarter, but a cell has
been designed that can be pumped on during the measurements in order to
have the required vapor density and yet avoid quenching in the presence
of foreign gas. It will be tested first with Li, and if the results are success-
ful, will then be used to complete this experiment on Na^{23} and Rb^{87}.

---

3. Level Crossing Experiments in the $^1P_1$ State of Cd*
   (A. Landman, A. Lurio,† R. Novick)

The enriched Cd^{113} sample has just arrived from England. While awaiting the sample, we have been assembling and testing polarizers. Several samples of PVA (polyvinyl alcohol) are being examined to see which will make the best circular polarizer for the 2288 Å line. A comparison of the Polacoat and Brewster's angle linear polarizers is also being carried out.

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4. Level Crossing Experiments in the $^1P_1$ State of Zn*
   (A. Landman, A. Lurio,† R. Novick)

The beam experiment has been set up. For further results, reference should be made to section I, F, infra, p. 14.

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5. Optical Detection of Level Crossings in the Stable Isotopes of Kr*
   (D. Landman, R. Novick)

All the apparatus for the experiment has now been assembled. Preliminary tests were made to produce and hold a vacuum in the resonance cell. These tests showed that the cell failed to hold a vacuum; we

attribute this failure to outgassing of the brass used in the cell construction and feed-in. Since it is not possible to bake out the cell because the LiF windows are epoxied on, we have redesigned the entire system so that all the feed-ins are pyrex and only the cell itself is brass. This new system is now being tested.

Program for the next interval: Tests of the experimental apparatus will be continued.

C. COHERENCE TIME MEASUREMENTS

1. Detection of Level Crossings in Backscattering*
   (R. J. Goshen, A. Landman, R. Novick)

No new measurements were made during the last quarter. An enriched sample of Cd^{106} has recently been received. It will be used with a sample of Cd^{114} which is already on hand to form the filter system for investigating selfbroadening, as described in the last Quarterly Report.

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2. High Field Measurements of the g Factors of the Alkali Earths by Double Resonance*
   (R. Kohler, P. Thaddeus†)

Double resonance in the $(5s\,5p)^3P_1$ state of the even cadmium isotopes has been observed at a frequency of 24 kMc and a magnetic field near 11 430 G. At this high field value, the $\Delta m = \pm 1$ components of the optical transition lie well outside the resonance line emitted by a lamp, and the $\Delta m = 0$ component alone is observed in resonance fluorescence.

Microwave resonance is then detected by a change in the angular distribution of the scattered light, most conveniently at 90°. Interaction with the neighboring fine structure states of the 5s 5p configuration is sufficient to separate the $\Delta m = \pm 1$ transitions by many times their line width. We have in fact observed two distinct resonances with a splitting of 9.5 G. A g factor of approximately 1.5002 was calculated.

Program for the next interval: It is expected that a precise measurement of the double resonance magnetic fields will permit a determination of g_J for the $^3P_1$ state to an accuracy of a few ppm, and allow comparison with the results of a level crossing experiment on the odd cadmium isotopes.[1]

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(1) P. Thaddeus and R. Novick, Phys. Rev. 126, 1774 (1962).

D. FINE STRUCTURE OF SINGLY IONIZED LITHIUM*
(P. Feldman, R. Novick)

The experimental program for the determination of the fine structure of the $2^3P_{0,2,1}$ state of Li^+ was described in the previous Quarterly Report.[1]

The design of the lithium ion source has been completed and is shown in Fig. 3. The entire system is contained within a stainless steel vacuum chamber which is surrounded by a pair of Helmholtz coils that produce a magnetic field, homogeneous to at least one part in 10^4 over a cubic inch at the focal point of the electron gun. The electron gun is of the Pierce type, and the Philips impregnated cathode has a maximum possible emission of 10 A/cm^2 at 1050°C. The lithium beam emerges from an oven with a deep crinkle foil slit producing a wide parallel beam which is directed against the electron beam into an equipotential box. Ions which are trapped along the magnetic field axis in the equipotential box are excited by a second collision with an electron, and the light is observed at
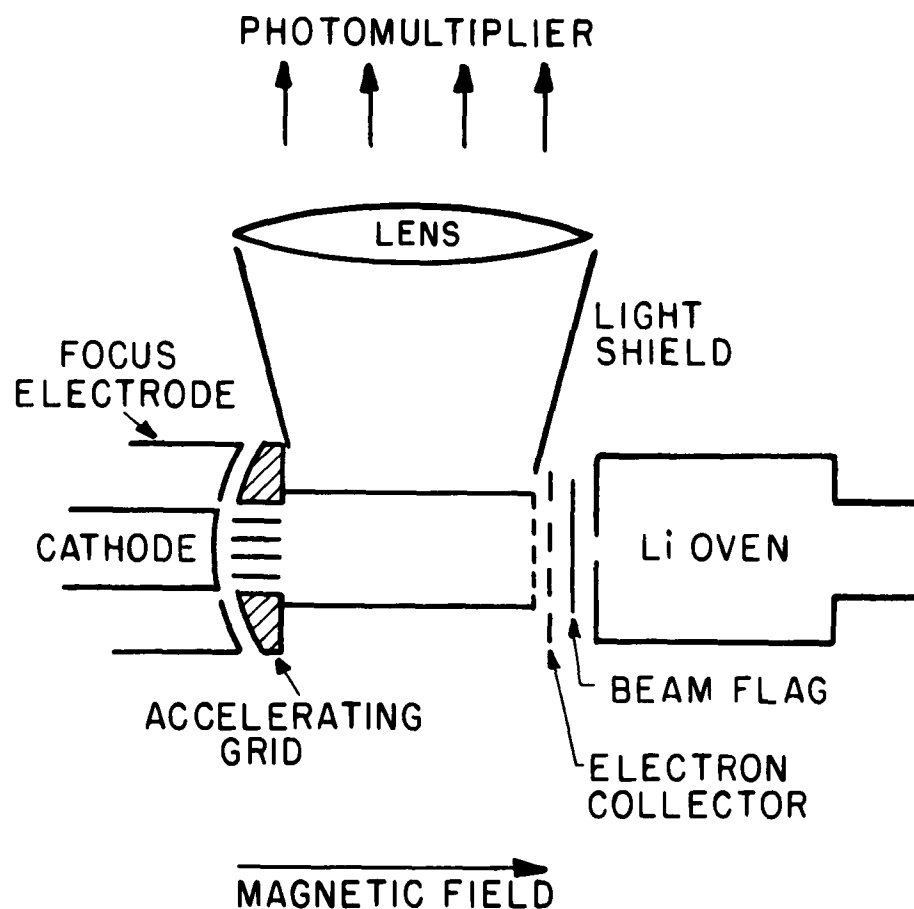
PHOTOMULTIPLIER

FIGURE 3. Schematic diagram of lithium ion source.

right angles to the box by means of a lens system and a photomultiplier tube. A narrow band interference filter centered at 5485 $\overset{\circ}{A}$ is placed between the lens system and the photomultiplier to select out light corresponding to the $2^3P_J \longrightarrow 2^3S_1$ transition, along with a filter strongly absorbent in the red, to reduce the background of blackbody radiation.

Program for the next interval: The vacuum system is ready for assembly and testing. Construction and assembly of the ion source described above should be completed by the end of the next quarter.

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(1) CRL Quarterly Report, Sept. 15, 1962, p. 11.

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E. THE METASTABLE LITHIUM ATOM*
(P. Feldman, R. Novick)

In the last Quarterly Report,[1] we described modifications in the experimental arrangement used to search for the $(1s\,2s\,2p)^4P_{5/2}$ state of lithium.

Fig. 4 shows the new detector and its position in the apparatus.

CONTROL GRID

COLLECTOR

SLITS

ELECTRON COLLECTOR

TARGET

LITHIUM OVEN

FOCUS ELECTRODE

FILAMENT

H

$2\times10^{11}\,\Omega$

TO
ELECTROMETER
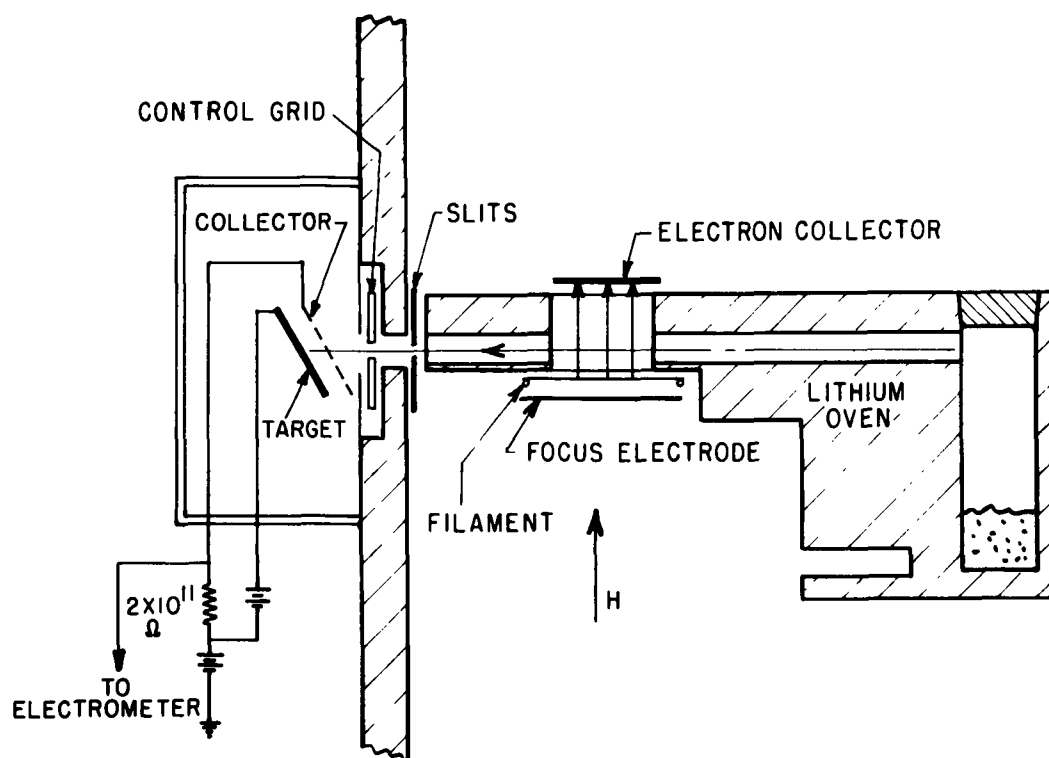
FIGURE 4. Lithium beam apparatus.
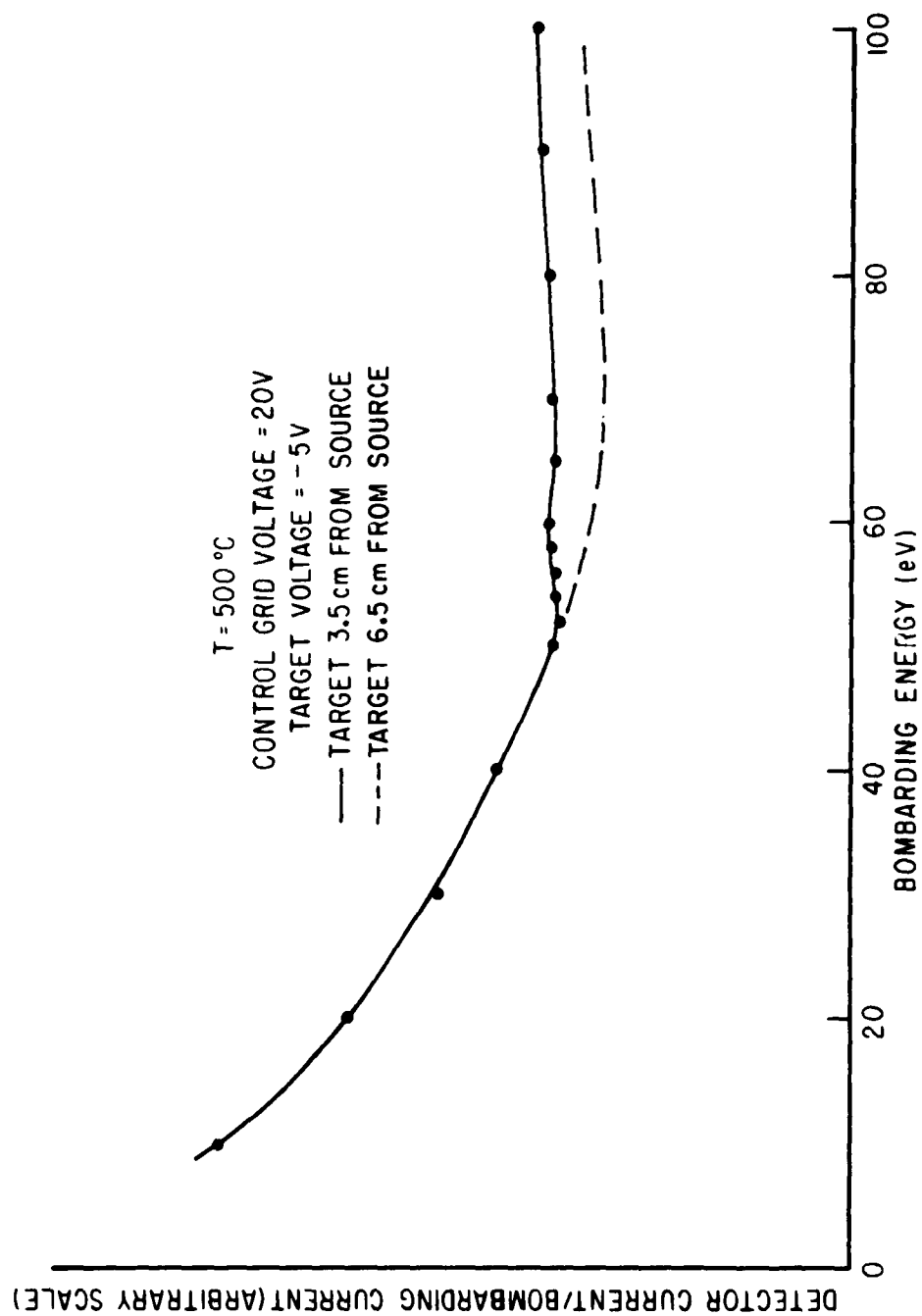
FIGURE 5. Lithium excitation curve as a function of bombarding energy.

Again we use a molybdenum plate as a target. Metastable atoms hitting the plate give rise to Auger electrons which are collected by the gridded collector. The target and collector are completely shielded by a copper box at ground potential, and a control grid serves to keep charged particles in the beam from entering the detector. The magnetic field for the electron gun also serves to deflect almost all of the charged particles (ions and electrons) from the beam. The only observed noise was the Johnson noise voltage developed across the 2×10^{11} Ω input resistor to the electrometer.

One shortcoming of this detector arrangement is its sensitivity to photons. Excited states of Li and Li$^+$ are produced in the beam by the bombarding electrons, and the short-lived states emit radiation in their decay to lower energy levels. Photons incident on the detector surface produce photoelectrons, which are collected in the same manner as the Auger electrons. The deposition of lithium on the target also complicates matters since its photoelectric work function is much smaller than that of molybdenum (2.2 eV for Li, 4.4 eV for Mo), so that the signal from soft photons increases with time when the beam is impinging on the target.

In several runs made during the quarter, we have observed the excitation curve of excited states of Li as a function of bombarding energy. Superimposed on this excitation curve (see Fig. 5) are two thresholds: the first at 55 eV energy is attributed to the metastable $(1s\,2s\,2p)^4P_{5/2}$ state, and the second near 65 eV arises from radiative decay of the lowest excited states of Li$^+$. The dotted curve in Fig. 5 shows the excitation curve when the detector was moved back 3 cm, the metastable signal being sharply reduced. Although no accurate quantitative measurements have been made yet, the signal belonging to the 55 eV threshold is consistent with the estimated properties of the $^4P_{5/2}$ state of lifetime $\approx 10^{-5}$ sec and production cross section $\sigma \approx 10^{-19}$ cm^2.

Quantitative measurements on the metastable state are not possible until the exact nature of the observed signal is determined. We have tried to separate the photons from metastable atoms and charged particles by inserting a thin organic film (collodion, styrofoam) in the beam path. However, the signal observed through the film was quickly damped out by deposition of Li, making the film opaque to photons as well.

At present we are developing a detector which will be insensitive to photons, but not to metastable atoms. The successful operation of

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this detector will also be evidence for the predicted decay scheme[2] of the $4P_{5/2}$ state into a ground state lithium ion and a free electron, since in principle we will collect only the charged decay products. Once the meta-stable signal is separated from the photon background, the detector can be made movable to permit an accurate measurement of the lifetime of the state.

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(1) CRL Quarterly Report, Sept. 15, 1962, p. 12.

(2) J. Pietenpol, Phys. Rev. Letters 7, 64 (1961).

F. MEASUREMENT OF THE LIFETIMES AND g_J FACTORS OF THE $^1P_1$ AND $^3P_1$ EXCITED STATES OF CALCIUM, STRONTIUM, AND ZINC*
(R. J. Goshen, A. Lurio,† R. de Zafra)

The measurement of the lifetimes of the $^1P_1$ states of Ca and Sr by observation of the Hanle effect in an atomic beam apparatus has been completed. An article will appear shortly in the Physical Review. We are extending this program to the Group II B elements, and preliminary results have already been obtained for the τ of the $(4s\,4p)^1P_1$ state of Zn. These values will be compared with those derived from experiments performed in a closed cell.[1] This check for consistent results is important because of the lack of agreement between our values and those reported in the Russian journals.

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(1) CRL Quarterly Report, June 15, 1962, pp. 8-10.

G. HYPERFINE STRUCTURE OF THE STABLE ISOTOPES Ca^{43} AND Sr^{87}*
(H. Bucka, R. J. Goshen, R. de Zafra)

The new double resonance spectrometer has been completely assembled. This apparatus has a Helmholtz pair capable of producing 800 G with a homogeneity of better than one part in 10^4 over a cubic inch. Flow and hollow cathode lamps are available as sources of 6574 Å radiation.

We have designed the geometry of the resonance cell and the optical system to reduce sources of noise to the lowest possible level. The $^3P_1 \longleftrightarrow {}^1S_0$ line at 6574 Å is in the far red. This presents a serious problem since radiation produced by the oven walls at high temperature will pass through the interference filter. A careful arrangement of aperture stops has been designed together with a rear window in the cell to prevent any of this radiation from reaching the photodetector. We have also provided liquid nitrogen cooling for the EMI photomultiplier to reduce the dark current substantially.

Program for the next interval: We will try to observe the low field Zeeman intervals in the 4^3P_1 state of Ca^{43}. If this is successful, we will measure the zero field hyperfine intervals directly.

H. FINE AND HYPERFINE STRUCTURE OF THE 3P STATE OF Li^7*
(B. Budick, R. J. Goshen, A. Landman, R. Novick)

With the dense atomic beam apparatus, shown schematically in the last report, we repeated earlier observations of the 2P low field level crossing. Because our first attempts to observe the 3P state were unsucessful, the following improvements were made in the apparatus:

1) The cylindrical oven was replaced by one of conical design. This is positioned just below the center of the apparatus and does not obstruct the focused light cones.

2) A beam flag was incorporated to help distinguish atomic from instrumental scatter.

3) Ports labeled "pumping" and "ion gauge" in the schematic were redesigned to provide viewing ports for observing scattering and absorption. The quartz windows used initially were quickly rendered opaque, and elbows with mirrors at 45° were installed to reflect light and condense atoms.

To test the new features and to determine the feasibility of the experiment, we decided to look for the Hanle effect in the 3P state. Subsequent failure in this attempt has led to a closer examination of our light sources.

Program for the next interval: We are engaged in a study of our hollow cathode source. Also, we are building a "leaky cell" which will be, in effect, a compromise between a dense beam and a cell.

I. SHARP FILTER FOR OPTICAL RESONANCE LINES FOR USE OF THE FARADAY EFFECT*
(R. Kohler, R. Novick)

Because our efforts have been concentrated during the past quarter on "High Field Measurements of the g Factors of the Alkali Earths by Double Resonance," supra, I, C, 2, p. 8, there is no progress to report on the filter project.

II. PROPERTIES OF RADIOACTIVE ATOMS

A. HYPERFINE STRUCTURE OF O^{15}*
(H. Feldman)

This report is a final discussion of our work on O^{15}. A comprehensive article on this work is being prepared for publication in the Physical Review.

Purpose

The magnetic dipole moments of mirror nuclei are quantities of particular interest in nuclear physics. It is thought that contributions to the magnetic dipole moment which result from mesonic currents can be eliminated by considering the sum of the moments of a mirror pair. This hypothesis, known as the "mirror theorem," states that the added moments due to mesonic currents are equal and opposite in a pair of mirror nuclei.[1] Consequently, one can hope to shed some light on nuclear structure by comparing the sum of the nuclear magnetic dipole moments of a mirror pair with the sums deduced from nuclear models.

The $(_7N^{15}, _8O^{15})$ mirror pair of mass 15 is especially conducive to analysis from the point of view of the nuclear shell model because these nuclei lack but a single nucleon from the "doubly closed" nucleus, $_8O^{16}$, in which the first two oscillator levels are filled for both protons and neutrons. The magnetic dipole moment of N^{15} is well known.[2] The purpose of this experiment was to ascertain the magnetic dipole moment of O^{15}. In order to accomplish this, the hyperfine splitting in the $^3P_2$ ground state of O^{15} was measured by the atomic beam magnetic resonance method. From this hyperfine splitting, $\Delta\nu(^3P_2, O^{15})$, the dipole coupling constant $A(^3P_2, O^{15})$ was deduced and then compared with the known values of $g_I(O^{17})$[3] and $A(^3P_2, O^{17})$[4] to obtain $g_I(O^{15})$ within an uncertainty due only to the hyperfine anomaly.

Experimental Procedure

O^{15} was produced by bombarding a gas target of N_2 with 5 MeV deuterons from the Columbia Van de Graaff accelerator. The stripping reaction $N^{14}(d, n)O^{15}$ yielded O^{15} atoms in the target gas, which consisted of approximately 150 mm N_2 and 2 mm NO. It was found necessary to add

the NO in order to prevent loss of the O^{15} atoms to the walls of the target chamber. Presumably the O^{15} atoms combined with the NO to form stable NO_2 molecules which were then allowed to flow through a needle valve and some twenty feet of 1/4 inch copper tubing into the source of a conventional atomic beam apparatus. Difficulty was encountered in preventing the thin foil which separated the target gas from the Van de Graaff vacuum from breaking. This problem was largely solved by using a 0.00025 inch molybdenum foil, covered with a thin coat of evaporated platinum on the gas side, and by wobbling the deuteron beam electrostatically to keep a hot spot from developing on the foil.

The source of the atomic beam apparatus consisted of a quartz tube with a 0.002 inch source slit sawed in its end. This tube was placed at a voltage antinode of a resonant cavity which was excited at 2460 Mc/sec by a Raytheon RK 5609 magnetron. The resulting discharge in the source gas (at a pressure ≈ 1.5 Torr) served to dissociate a substantial fraction of the molecules so that a beam of O^{15} atoms was formed (together with a large beam of N_2 and NO).

The deflection system of the atomic beam apparatus was arranged in the "flop-in" manner so that atoms reached the detector only if they had undergone a transition in the "C" field such that the sign of their high magnetic field magnetic dipole moment was reversed. A stop wire was placed in such a manner as to cast a geometric shadow on the detector channel in order to prevent O^{15}-bearing molecules and $M_J = 0$ O^{15} atoms from reaching the detector.

The detector chamber was separated from the main chamber by a channel flaring from 0.045 inch to 0.125 inch (called the detector channel above). At the end of the detector chamber was a plate which could be rotated on an "O"-ring seal about an axis 2 3/8 inches below the beam center. On this plate were mounted six molybdenum foils 0.001 inch thick with their centers equispaced on a circle of radius 2 3/8 inches whose center was on the axis of rotation. While one of these foils was in position to receive the beam, another, displaced from it by 60°, was being coated with fresh barium from an oven placed inside the detector chamber. When rotated into the beam position, this foil then trapped the O^{15} atoms from the beam without allowing them to bounce. A plastic scintillator and photomultiplier were placed immediately outside the vacuum envelope opposite

the beam. Pulses arising from the positrons, which were emitted by the O^{15} atoms ($\tau_{1/2}$ = 124 sec) and which had passed through the molybdenum foil, were recorded and constituted the observed signal. The usual procedure was to count while collecting for 3 min (the order of the O^{15} half-life), insert a beam stop, change the radio frequency, rotate the detector wheel 60°, remove the beam stop, and start counting again. Before and after observing an O^{15} resonance, the magnetic field was calibrated by observing the two-quantum Zeeman resonance, (M = - 1) $\longleftrightarrow$ (M = 1), in the $^3S_1$ metastable state of helium. The metastable helium atoms were formed in the same discharge source used to obtain O^{15} atoms, and the beam was detected by observing the current due to Auger ejection of electrons from a metallic surface when the metastable atoms impinged on it.

Results

The two-quantum Zeeman resonances, (F = 5/2, M_F = 1/2) $\longleftrightarrow$ (F = 5/2, M_F = - 3/2), and (F = 3/2, M_F = 3/2) $\longleftrightarrow$ (F = 3/2, M_F = - 1/2), in the $^3P_2$ ground state of O^{15} were observed at low magnetic field on numerous occasions. The ratios of these resonant frequencies to the frequency of the $^3S_1$ helium resonance were consistent only with the expected result that the spin of O^{15} is one half.[5] The known values of g_J ($^3P_2$, O^{15}) (measured in O^{16}) and g_J ($^3S_1$, He^4) were used.[6,7]

Measurements of the F = 5/2 two-quantum Zeeman resonance were carried out at intermediate magnetic fields in order to obtain an approximate value of Δv. These measurements yielded the result Δv = 1040 ± 20 Mc/sec, enabling us to narrow the range of search for the ΔF = 1 transition, (F = 5/2, M_F = 1/2) $\longleftrightarrow$ (F = 3/2, M_F = - 1/2). This step was required to conserve Van de Graaff time.

Finally the (F = 5/2, M_F = 1/2) $\longleftrightarrow$ (F = 3/2, M_F = - 1/2) transition was sought, found, and its frequency measured. On the basis of over thirty measurements at various magnetic fields up to approximately 7.5 G, we arrived at the value:

$$\Delta v = 1037.23 \pm 0.07 \text{ Mc/sec.}$$

The precision was limited by the presence of severely distorted line shapes, due to field inhomogeneity, and to a generally poor signal-to-noise ratio.

In a typical run we would observe a maximum "flop" of about 120 counts in 3 min on a background of about 1200 counts with nonstatistical fluctuations roughly as large as the "flop." From this value of $\Delta\nu$ ($^3P_2$, O^{15}) we obtain the value

$$A(^3P_2, O^{15}) = 414.87 \pm 0.03 \text{ Mc/sec,}$$

after applying a correction of -46 kc/sec to $\Delta\nu$ arising from the mixing of the $F = 3/2$ levels in the $^3P_2$ and $^3P_1$ states by virtue of the hyperfine interaction. From this value of $A(^3P_2$, $O^{15})$ we then obtain $\mu(O^{15})$ from the simple relationship:

$$\frac{A(^3P_2, O^{15})}{A(^3P_2, O^{17})} \cong \frac{2\mu(O^{15})}{g_I(O^{17})}$$

The value of $\mu(O^{15})$ is 0.7186 nm and is subject to the uncertainty arising from the $O^{15} - O^{17}$ hyperfine anomaly.

<div align="center">Discussion</div>

The hyperfine anomaly should not be exceedingly large for two reasons. First, both O^{15} and O^{17} may be presumed to have magnetic dipole moments which arise almost wholly from nucleon spin rather than from orbital angular momentum. This is due to the fact that the eight protons in each case are, from the point of view of the shell model, coupled to zero angular momentum, whereas the uncharged neutrons do not contribute any magnetic moment due to orbital motion. Thus, the primary contribution to the hyperfine anomaly, as discussed by Bohr and Weisskopf,[8] is zero.

Second, the electronic state of the atom arises from the $2p^4$ configuration, so that the unpaired electron density at the nucleus is very small (0 nonrelativistically). A conservative upper limit on the hyperfine anomaly is

$$|\Delta| \equiv \left| \frac{A(O^{15})/A(O^{17})}{g(O^{15})/g(O^{17})} - 1 \right| < 0.001$$

We can then assign an uncertainty to $\mu(O^{15})$:

$$\mu(O^{15}) = 0.7186 \pm 0.0008 \text{ nm}$$

The sum of the moments of O^{15} and N^{15} can now be compared with theory:

	μ (Schmidt)	μ (exp.)	Deviation
O^{15}	+ 0.638 nm	+ 0.719 nm	+ 0.081 nm
N^{15}	– 0.264 "	– 0.283 " (a)	– 0.019 "
Sum	+ 0.374 "	+ 0.436 "	+ 0.062 "

(a) L. W. Anderson, F. M. Pipkin, and J. C. Baird, Phys. Rev. <u>116</u>, 87 (1959).

The deviation of the sum of the moments from the sum of the Schmidt values, + 0.062 nuclear magnetons, is quite small and cannot be explained quantitatively at this stage in our understanding of nuclear structure. Nevertheless, one should be able to show that this deviation is not implausible. One might think that it can be explained easily by assuming some mixture of shell model states to be the actual nuclear wave function instead of the pure $P_{1/2}$ single particle state. This, however, is not the case. No single particle excitation of the odd nucleon can help since only higher $P_{1/2}$ states can be admixed due to the requirements that the nuclear spin be one half and the parity be odd. No admixture of excitations of the odd group of nucleons can give the required deviation unless we assume that the mesonic contributions are exceedingly large (larger in absolute value than the N^{15} moment). The deviation can be explained by assuming the admixture of excited states of the even-nucleon core, or mixed excitations of one proton and one neutron, but these states do not contribute to the change of moment in first order (since the magnetic moment operator has non-zero matrix elements only between states which differ with respect to no more than one particle). Consequently one would have to assume surprisingly large admixtures of states of high energy in order to obtain the necessary deviation. A plausible explanation is found in the suggestion of Jensen and Mayer[9] that the theoretical single particle moment of an odd proton nucleus should be modified by the

contribution of an effective moment due to the large spin-orbit interaction in nuclei. A rough calculation of this effect in N^{15} yields a contribution of approximately + 0.10 nm which is more than sufficient to explain the deviation. In any case, it is apparent that the value obtained for $\mu(O^{15})$ does not present a conflict with our theoretical knowledge at this time and that any precise quantitative explanation of it must await further developments in the theory.

Program for the next interval: Work on O^{15} has been completed. The atomic beam apparatus is being moved to a new location to make room for other equipment associated with the Van de Graaff accelerator. A similar experiment on atomic F^{17} is planned with the atomic beam apparatus, and improvements in the "C"-magnet and the detector are being considered.

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(1) R. G. Sachs, Nuclear Theory (Addison Wesley, Cambridge, Mass., 1954).

(2) L. W. Anderson, F. M. Pipkin, and J. C. Baird, Phys. Rev. 116, 87 (1959).

(3) F. Alder and F. C. Yu, ibid. 81, 1067 (1951).

(4) J. S. M. Harvey, private communication.

(5) Previous reports on this research are: E. D. Commins and H. R. Feldman, Bull. Am. Phys. Soc. 6, 73 (1961); H. R. Feldman and E. D. Commins, ibid. 7, 476 (1962), as well as previous issues of the CRL Quarterly Progress Report.

(6) H. E. Radford and V. W. Hughes, Bull. Am. Phys. Soc. 3, 8 (1958).

(7) C. Drake, A. Lurio, V. W. Hughes, and J. A. White, ibid. 3, 7 (1958).

(8) A. Bohr and V. F. Weisskopf, Phys. Rev. 77, 94 (1950).

(9) J. H. D. Jensen and M. Mayer, ibid. 85, 1040 (1952).

B. HYPERFINE STRUCTURE OF EXCITED STATES OF Na ISOTOPES*
(R. J. Goshen)

We are still confronted with the problem of finding windows for our resonance cell which are resistant to attack by alkali metals at high temperature and yet have acceptable transmission at 2853 Å. This difficulty has been overcome for the case of the alkaline earths, where the intercombination lines lie in the far red, by the use of MgO windows and crystals. At 2853 Å the presence of impurities reduces the optical transmission coefficient of MgO to poor or marginal values. However, manufacturing processes are improving, and we shall continue to test MgO crystal and window samples for useful transmission at ultraviolet wavelengths. Other materials are also being investigated for resistance to alkali attack and for the required optical properties.

C. OPTICAL DOUBLE RESONANCE STUDIES OF RADIOACTIVE ATOMS*
(F. Byron, R. Novick, B. Perry)

In the last quarter experimental work on 245 day Zn^{65} and 43 day Cd^{115m} has been completed. Zero field direct measurements of the $^3P_1$ hfs of Zn^{65} were made giving:

$$F = 7/2 \longrightarrow F = 5/2 \qquad \gamma_1 = 1875.468(1) \text{ Mc} \ ,$$
$$F = 5/2 \longleftarrow F = 3/2 \qquad \gamma_2 = 1334.206(4) \text{ Mc} \ ,$$
$$A = 535.192(1) \text{ Mc} \ ,$$
$$B = 2.865(3) \text{ Mc} \ ,$$
$$\mu = +\ 0.768(7) \text{ nm} \ ,$$
$$Q = -\ 0.023(2) \text{ b} \quad .$$

The values of A and B include the second order fine structure corrections to the hfs. The values of μ and Q do not include the effects of nuclear struc-

ture or quadrupole antishielding. The quoted errors are estimates of the size of these effects.

Circular polarization measurements in the $F = 13/2$ $^3P_1$ hfs level of Cd^{115m} give the magnetic moment as negative. A Cd^{113} lamp was used in this experiment because of the proximity of the $F = 3/2$ state of Cd^{113} to the $F = 13/2$ state of Cd^{115m}. At high fields the $m_F = 13/2, 11/2$ states were split to receive maximum illumination, and resonances between these states were observed. The results from these measurements, combined with the previous ones in the $F = 11/2$ state, are:

$$A = -657.(4) \quad Mc/sec \quad ,$$

$$B = +130.7(28) \; Mc/sec \quad ,$$

$$\mu = -1.04(1) \; nm \quad ,$$

$$Q = -0.60(6) \; b \quad .$$

These results do not include second order fine structure corrections or corrections for nuclear structure and quadrupole antishielding.

The 15 yr Cd^{113m} samples which were made at the MTR and described in previous reports are still under study. The extremely low radioactivity of the samples (99.9% 512 keV β^-, 0.1% 265 keV γ) makes tracing the atoms extremely difficult. A second resonance cell has been made and is currently under study.

Preparations are being made for a Cd^{114} (n,γ) Cd^{115} irradiation at the MTR. The lifetime, 2.3 days, makes separation of the Cd^{115} from the Cd^{114}, as was done with Cd^{115m}, impossible. Study of this isotope is especially important in view of the anomalies noted in Cd^{111} and Cd^{113}.

A theoretical study of the nuclear properties of zinc and cadmium was undertaken in the last quarter. The comparison of experimental data on nuclear moments with theory is severely handicapped by the fact that there is no rigorous theory. In lieu of a working theory of nuclear matter one resorts to models, and in particular, the shell model has met with considerable success in explaining the spins and magnetic moments of nuclei, although its failure in accounting for large positive quadrupole moments is well known. In its simplest form, the shell model postulates the nucleons moving

independently in a central potential well. To fit observed nuclear data the following potential is usually adopted:[1]

$$U(r_i) = \frac{1}{2} m \omega^2 r_i^2 - a \, \vec{\ell_i} \cdot \vec{s_i} - b \ell_i^2 \quad ,$$

where i refers to the ith nucleon and a and b are adjustable parameters used to fit the level ordering to the observed order (the well known "magic numbers," for example). One can now proceed along essentially atomic physics lines, and if we neglect the obvious two-body correlation corrections to $U(r_i)$, a rather simple theory results which for moments gives the familiar Schmidt lines, i.e., the moments are due to the odd nucleon alone, with obvious corrections for identity effects if necessary. Taking for the dipole moment (in units of nuclear magnetons, $e\hbar/2\,Mc$),

$$\vec{\mu l} = g_\ell \, \vec{\ell_i} + g_s \, \vec{s_i}$$

with $\quad g_\ell = 1$ for protons, 0 for neutrons,

and $\quad g_s = +5.59$ for protons, -3.83 for neutrons,

and $\quad Q_i^{(\mu)} = 2 e \, r_i^2 \, C_\mu^{(2)} (\theta_i, \phi_i)$

for the quadrupole moment, where $C_\mu^{(2)}$ is the unnormalized spherical harmonic of Edmonds,[2] one readily obtains the Schmidt results:

$$\mu = \langle j^n \, J = M = j \, | \mu_z | \, j^n \, J = M = j \rangle$$

$$= \left[g_\ell \pm (g_s - g_\ell) \right] \frac{j}{2\ell + 1} \quad , \text{ for } j = \ell \pm \frac{1}{2} \, ;$$

$$Q = \langle j^n \, J = M = j \, | Q_i^{(o)} | \, j^n \, J = M = j \rangle$$

$$= -e \, \frac{2j + 1 - 2n}{2j + 2} \, \langle j \, | r^2 | \, j \rangle \quad ,$$

where n is the number of identical particles with the given j, and $<j|r^2|j>$ is the average value of r^2 in the state j. Note that as an estimate one may use $<j|r^2|j> = 3/5\ R^2$, where R is the nuclear radius given by

$$R = 1.2 \times 10^{-13} A^{1/3} \text{ cm} \quad ,$$

A being the number of nucleons. In this model, odd neutron nuclei have no quadrupole moments, which is grossly incompatible with experiment. One sees immediately that on this model the largest quadrupole moments possible (A ≈ 250) are of the order of 0.3 barns (where we omit the charge e), and that negative quadrupole moments are as likely as positive ones. This is completely out of keeping with the experimental situation where Q's are found to be predominately positive and Q's of order 1 - 10 barns are often found. As is well known, the situation is much better for Schmidt magnetic moments where the sign and order of magnitude are generally correct. It is for this reason that attempts have been made to improve the shell model by mixing in other configurations with the simple shell model ground state to obtain an "improved ground state wave function" which will then be used to compute a presumably "improved" moment. Perhaps the most comprehensive attempt has been that of Arima and Horie[3] who consider a residual two-body perturbation of the form

$$V = \sum_{i > j} v_{ij}$$

Then the shell model ground state $|o>$ will become, via first order perturbation theory,

$$|o'> = |o> - \sum_n \frac{<n|\sum_{i>j} v_{ij}|o>}{E_n - E_o} |n> \quad ,$$

where E_n, E_o are unperturbed shell model energies. The matrix element of any operator O in the new ground state will be just

$$<o'|O|o'> = <o|O|o> - 2 \sum_n \text{Re} \frac{<n|\sum_{i>j} v_{ij}|o>}{E_n - E_o} <o|O|n>$$

keeping only first order terms and assuming not all $<o|O|n>$ vanish (n refers to all quantum numbers necessary to specify a given configuration).

Thus we see that with a relatively small percentage of admixed states, we can get very large corrections to $< o \, |O| \, o >$ because of interference terms. Assuming

$$v_{ij} = \left[V_0 + V_1 \, \overrightarrow{\sigma_i} \cdot \overrightarrow{\sigma_j} \right] \, \delta \, (\overrightarrow{r_{ij}})$$

and

$$V_1 / V_0 \approx 0.1$$

(from free nucleon data), there is only one adjustable parameter, which can be related to the "pairing energy":

$$P_j = - < j^2 \, o \, \left| v_{12} \right| \, j^2 \, o > \; .$$

Experimental values of the pairing energy enable one to determine a reasonable range of values for the theory's parameter. Arima and Horie find a rather good agreement between experimental and theoretical magnetic moments using values of the parameters consistent with experimental data on pairing energies.[3] We have used the tables and results of Arima and Horie to calculate the magnetic dipole moments of those zinc and cadmium isotopes which it seems feasible to measure on the present apparatus. The results are shown in Table I, along with results for moments which have already been measured. The rather good agreement between experiment and theory should perhaps not be taken too seriously, but only as a suggestion that the experimental results are quite reasonable.

The theoretical quadrupole moments for zinc in Table I are also obtained by the method of Arima and Horie. The theoretical quadrupole moments for cadmium were calculated by using the experimental value for Cd^{107} to determine Q_0, where we assume

$$Q = \left(\frac{2j + 1 - 2n}{2j + 2} \right) Q_0 \qquad ,$$

i.e., we assume that because we have an odd neutron case and the entire moment comes from a large number of small corrections due to various possible proton excitations, we may hope that the entire j and n dependence

TABLE I. Theoretical vs experimental values of magnetic dipole moments and quadrupole moments of zinc and cadmium isotopes.

Isotope	Main Configuration	Spin	μ (exp) in μ$_B$	μ (Sch) in μ$_B$	μ (th) in μ$_B$	Q (exp) in barns	Q ("th") in barns
$_{30}Zn^{63}_{33}$	$(2p_{3/2})^4 (1f_{5/2})^1$	5/2		+ 1.37	+ 0.45		− 0.17
	$(2p_{3/2})^3 (1f_{5/2})^2$ (↑)	3/2	?	− 1.91	− 0.07	?	+ 0.12
$_{30}Zn^{65}_{35}$	$(2p_{3/2})^4 (1f_{5/2})^3$	5/2	+ 0.77[a]	+ 1.37	+ 0.72	− 0.026[a]	0.00
$_{30}Zn^{67}_{37}$	$(2p_{3/2})^4 (1f_{5/2})^5$	5/2	+ 0.88[b]	+ 1.37	+ 0.99	+ 0.16[c]	+ 0.17
$_{48}Cd^{107}_{59}$	$(2d_{5/2})^5 (1g_{7/2})^4$	5/2	− 0.62[d]	− 1.91	− 0.64	+ 0.78[d]	+ 0.78
$_{48}Cd^{109}_{61}$	$(2d_{5/2})^5 (1g_{7/2})^6$	5/2	− 0.83[e]	− 1.91	− 0.76	+ 0.80[e]	+ 0.78
$_{48}Cd^{111}_{63}$	$(2d_{5/2})^6 (1g_{7/2})^6 (3s_{1/2})^1$	1/2	− 0.60[f]	− 1.91	− 0.85	0	0
$_{48}Cd^{111(*)}_{63}$	$(2d_{5/2})^5 (1g_{7/2})^6 (3s_{1/2})^2$ (↑)	5/2	− 0.78[g]	− 1.91	− 0.76	?	+ 0.78
$_{48}Cd^{113}_{65}$	$(2d_{5/2})^6 (1g_{7/2})^8 (3s_{1/2})^1$	1/2	− 0.62[f]	− 1.91	− 0.99	0	0
$_{48}Cd^{113m}_{65}$	$(2d_{5/2})^6 (1g_{7/2})^8 (3s_{1/2})^0 (1h_{11/2})^1$	11/2	?	− 1.91	− 1.29	?	− 1.05
$_{48}Cd^{115}_{67}$	$(2d_{5/2})^6 (1g_{7/2})^8 (3s_{1/2})^1 (1h_{11/2})^2$	1/2	?	− 1.91	− 0.89	0	0
$_{48}Cd^{115m}_{67}$	$(2d_{5/2})^6 (1g_{7/2})^8 (3s_{1/2})^0 (1h_{11/2})^3$	11/2	− 1.04[a]	− 1.91	− 1.11	− 0.60[a]	− 0.63

(*) This is the 85 ns excited state.

(↑) This seems by far the most likely of the two configurations on the basis of nuclear data.

(↑) On the basis of nuclear considerations, this assignment seems quite likely.

(a) F. Byron, M. N. McDermott, B. Perry, and R. Novick, CRL Quarterly Progress Report, Sept. 15, 1962, pp. 23–25.

(b) S. S. Dharmatti and H. F. Weaver, Jr., Phys. Rev. 85, 927 (1952).

(c) A. Lurio, Phys. Rev. 126, 1768 (1962).

(d) F. Byron, M. N. McDermott, R. Novick, and B. Perry, CRL Quarterly Progress Report, Dec. 15, 1961, pp. 29–32.

(e) M. N. McDermott and R. Novick, CRL Quarterly Progress Report, Mar. 15, 1961, pp. 36–38.

(f) W. G. Proctor and F. C. Yu, Phys. Rev. 76, 1728 (1949).

(g) R. M. Steffan and W. Zobel, Phys. Rev. 103, 126 (1956).

Note: In the experimental results for Q all the figures quoted are expected to be accurate to no more than about 10%. In the magnetic moments all save Cd^{115m} and Cd$^{111(*)}$ are accurate to less than 1%. Cd^{115m} is good to about 1%, Cd$^{111(*)}$ to about 4%.

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will be contained in the projection factor $\left(\dfrac{2j + 1 - 2n}{2j + 2}\right)$ and that Q_o will depend only on the number of protons Z. We have resorted to this artifice in view of the fact that a straightforward approach, even including configurational mixing, does not seem likely to yield anything approaching the observed values of Q in cadmium (Q $\approx$ 1 b). In cadmium, it is well known that there is a considerable distortion of the nuclear shape and that there are very clear vibrational characteristics in the levels spectrum of the even-even cadmium nuclei; i.e., there is undoubtedly considerable collective motion even in so light a nucleus as cadmium, and it would appear that the simple shell model is essentially powerless to discuss quadrupole moments in this case. If one makes the above assumption to calculate the quadrupole moment of Zn^{65} from that of Zn^{67}, one gets the same result as one does from carrying through the Arima-Horie method, which perhaps gives some slight credibility to this approach. Again, such agreement as there is may be fortuitous.

Further examination of the collective aspect of these nuclei is in progress.

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(1) S. G. Nilsson, Dan. Mat.-Fys. Medd. 29, No. 16 (1955).

(2) A. R. Edmonds, Angular Momentum in Quantum Mechanics (Princeton Univ. Press, 1957).

(3) H. Noya, A. Arima, and H. Horie, Supp. Progr. Theoret. Phys. 8, 1958.

D. HYPERFINE STRUCTURE OF Ca^{41} AND Ca^{45}*
(H. Bucka, R. J. Goshen, R. Novick, R. de Zafra)

Thus far we have been unable to obtain the required enrichment of our $Ca^{41}O$ sample by mass spectroscopic isotope separation. The prospects for completing this enrichment soon are not encouraging. We shall therefore attempt to proceed with the experiment using our present sample. This will

require several refinements in our apparatus and technique including the use of source broadening and isotope filters to take advantage of the isotope shift between Ca^{40} and Ca^{41}.

The hollow cathode light source has been constructed and tested and appears to have good intensity in the $^3P_1$ ⟶ $^1S_0$ 6575 Å intercombination line.

E. OPTICAL DETECTION OF LEVEL CROSSINGS IN THE $(4s\,4p)^3P_1$ STATE OF Zn^{65}*
(A. Landman)

The major and the two strongest of the foldover crossings have been observed for this radioactive isotope of zinc. The magnetic field values at which crossing was observed to occur, measured in units of the nuclear magnetic resonance frequency of protons in mineral oil, together with the low field assignment of the levels are:

(F, m_F) = $(7/2, -7/2)$ and $(5/2, -3/2)$ at 3253.52 ± 0.06 kc/sec;

(F, m_F) = $(5/2, 1/2)$ and $(5/2, -3/2)$ at 3238.0 ± 0.3 kc/sec;

(F, m_F) = $(5/2, 3/2)$ and $(5/2, -1/2)$ at 3221.9 ± 0.4 kc/sec.

A hand-fitting procedure is now being undertaken to include the second order fine structure corrections in the calculation of the hyperfine coupling constants from the crossing point fields.

III. PHYSICS OF MOLECULES

A. MASER BEAM SPECTROSCOPY*
(L. Krisher, P. Thaddeus[†])

The experimental data on the $2_{2,0} - 2_{2,1}$ transition of the HDS molecule at 11 284 Mc have been analyzed using the computation facilities of the Institute of Space Studies. The "best fit" to the experimental results involves the following parameters:

$$eq_J Q(2_{2,0}) = 42.90(36) \text{ kc/sec},$$
$$eq_J Q(2_{2,1}) = 43.32(37) \text{ kc/sec},$$
$$C_H(2_{2,0}) = -25.03(13) \text{ kc/sec},$$
$$C_H(2_{2,1}) = -25.45(13) \text{ kc/sec},$$
$$C_D(2_{2,0}) = -0.47(2) \text{ kc/sec},$$

and
$$C_D(2_{2,1}) = -0.22(2) \text{ kc/sec}.$$

In this calculation the direct spin-spin interaction, a_s, was assumed from the geometry of HDS given by Bird and Townes.[1]

Program for the next interval: During the next quarter a maser cavity, thermally stabilized by an electronic circuit, will be constructed. The klystron frequency stabilizer described in section III, D, infra, p. 35, will be used to search for the 0 - 1 transition of the CH_3CN molecule.

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(1) Bird and Townes, Phys. Rev. 94, 1203 (1954).

[†]NASA Institute for Space Studies.
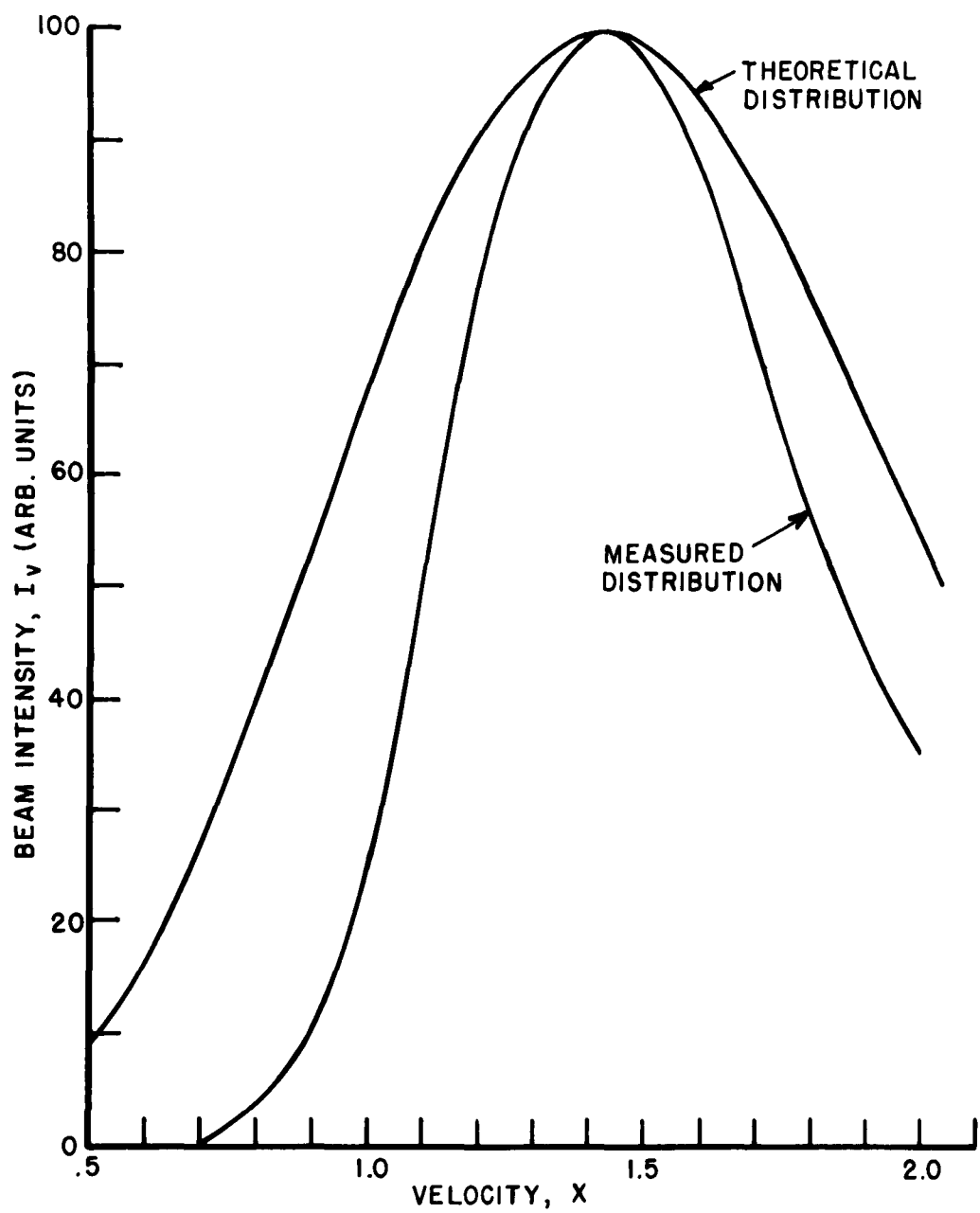
FIGURE 6. Velocity distribution of potassium (beam intensity vs velocity).

B. MICROWAVE ABSORPTION SPECTROSCOPY*
(L. Krisher)

A further study of the spectrum of acetyl iodide was made during the last quarter.

C. MOLECULAR BEAM VELOCITY SELECTOR*
(M. Hessel, P. Kusch)

In preparation for the $K-N_2$ scattering experiments described in a previous report, velocity distributions (potassium beam intensity vs velocity of potassium atoms) were measured with no gas admitted to the scattering chamber. The velocity distribution of the molecules in a beam coming from an oven through the velocity selector was shown by Miller and Kusch [1] (MK) to be consistent with a Maxwellian distribution in the oven. The predicted distribution and a typical measured one, normalized at maximum beam intensity, are shown in Fig. 6. The measured distribution is much narrower than the predicted one. Dimerization or impurities in the beam material would tend to broaden the curve. The beam intensity at the detector I_v should be, under the assumption of a Maxwellian distribution in the oven,

$$I_v = 2 g I_o x^4 \exp (- x^2) ,$$

where I_o is the total beam intensity at the detector when the velocity selector is removed, g is a fixed geometric property of the velocity selector (about 1/20), and $x^2 = mv^2/2kT$, in which v is the center of the velocity band transmitted by the selector.

A schematic diagram of the present apparatus is shown in Fig. 7. Since the experiments of MK, the scattering chamber section and the deflecting magnets have been added. In the present experiment a 92% Pt: 8% W filament has been used for the hot wire detector instead of the pure W used by MK.
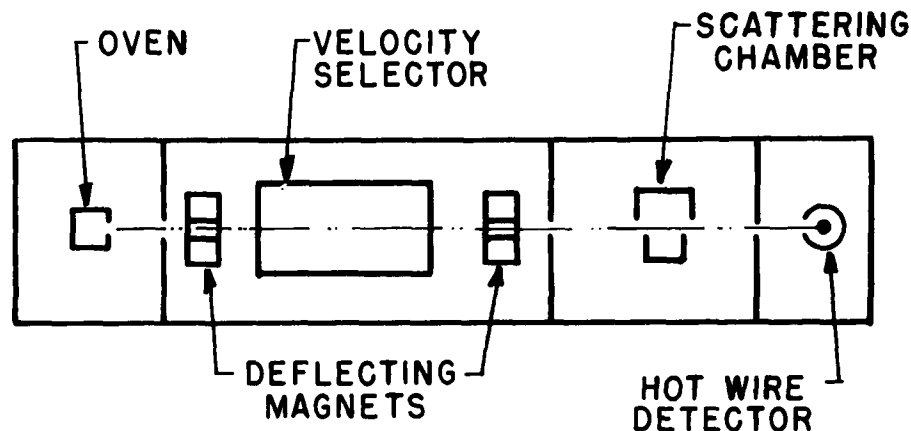
FIGURE 7. Molecular beam velocity selector.

Four separate oven loads of potassium have been used, one with distilled K and the other three with commercial lump K. Both a high conductivity copper oven of the same design as that used in the MK experiments and a nickel oven of somewhat different geometry were used in the present experiment. Velocity distributions were also taken with and without the scattering chamber in the path of the beam and with varying beam intensities. None of the above changes seemed to affect the shape of the measured distribution.

Scattering of the beam of atoms does cause a deficiency of low velocity atoms. Calculations and an experiment in which the K beam was scattered from H_2 could not account for the change in the velocity distribution.

Program for the next interval: We plan to try to determine the cause of the anomalous velocity distribution by:

1) Converting to a pure tungsten filament,

2) Investigating the deflecting magnets to see if there is residual magnetism (this would preferentially deflect low velocity molecules),

3) Using a different molecule such as KCl, and

4) Looking at the beam profile (beam intensity vs detector posi-
tion) to see if there are velocity-dependent reflections from the velocity
selector or other parts of the apparatus.

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(1) R. C. Miller and P. Kusch, Phys. Rev. 99, 1314 (1955).

D. MOLECULAR BEAM ELECTRIC RESONANCE SPECTROSCOPY*
(P. Cahill, P. Gold)

The object of this program[1] is the measurement of the microwave
and rf spectra of simple molecules by the molecular beam electric resonance
method. The immediate goals are the construction of the spectrometer and
the measurement of the microwave spectrum of lithium chloride.

During the past quarter the vacuum system, described in a previous
report,[2] was completed and placed in operation. The two sections of the
vacuum tank are each equipped with a 6-inch oil diffusion pump and a baffle
cooled by a Freon 12 refrigeration system; in the main section a liquid nitro-
gen trap is placed between the baffle and the vacuum tank. After 3 1/2
days of continuous pumping, the measured pressures were 2×10^{-7} Torr in
the source section and 5×10^{-9} Torr in the main section as measured with
Veeco RG-75 ionization gauges. The tank was not baked during this time;
the construction permits baking, however, should it later prove desirable.

Design of the internal components of the spectrometer is complete
and their construction is in progress.

A circuit for phase locking a reflex klystron to a Gertsch FM-4
rf oscillator has been constructed. The Gertsch oscillator is phase locked
at 20 Mc intervals to harmonics of the CRL frequency standard. A K-band
klystron may be swept over a 10 Mc frequency range by varying the frequency
of the rf reference input to the klystron phase-lock circuit.

Program for the next interval: Construction of the spectrometer components will continue, and their assembly and testing will begin. Design, construction, and testing of the electronics will continue.

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(1) CRL Quarterly Report, March 15, 1962, p. 45.

(2) CRL Quarterly Report, June 15, 1962, p. 41.

IV. SOLID STATE PHYSICS

A. THE INTERACTION BETWEEN A NEUTRAL MOLECULE AND A CONDUCTING SURFACE*
(F. Cook)

A change of personnel has necessitated the postponement of this project.

B. ENDOR AND OPTICAL STUDY OF COLOR CENTERS*
(I. Bass, R. Gazzinelli, R. Marzke, R. Mieher)

1. Superheterodyne ESR Spectrometer

Work has continued on the ESR spectrometer described in the last Quarterly Report for the detection of Electron Nuclear Double Resonance (ENDOR).

The ENDOR technique requires a third field H_2 in addition to the constant field H_0 and the microwave field H_1. H_2 must be perpendicular to H_0 and must oscillate in the frequency region from 1 Mc to approximately 100 Mc. This rf field is generated by an oscillator whose tank circuit coil couples inductively directly to a Helmholtz coil inside the microwave cavity. The rf oscillator is 100% square wave modulated by a modulator driven by the same audio oscillator that is used in the modulation of the H_0 field in the observation of ESR. The signal is detected in the usual manner by a phase sensitive demodulator followed by a lock-in amplifier whose reference is the audio frequency that modulates the rf field.

The microwave cavity is a tuneable cylindrical cavity operating in the TE_{011} mode. The lateral surface of the cavity is made of silver-coated quartz and the top and bottom surfaces of gold-plated brass. The cavity is magnetically coupled to the wave guide by an iris in the top surface. The sample is placed inside a quartz finger in the center of the cav-

ity and is cooled to liquid nitrogen temperature by thermal conduction. Two loops inside the cavity that surrounds the sample create the H_2 field necessary for the nuclear transitions.

Observation of ENDOR signals in F centers in KCl are now being made and are used as a standard for the improvement of the sensitivity and reproducibility of the spectrometer. We expect in the next quarter to start to use the spectrometer in the study of color center problems.

2. Double Nuclear Magnetic Resonance

Preliminary measurements have been started on the effects of strong rf fields on solid state nuclear magnetic resonance. The equipment used is a bridge-type spectrometer with a stable rf oscillator feeding a bridge containing the sample coil in one arm and a dummy tank circuit in the other arm (see Fig. 8). The bridge unbalance due to the nuclear resonance is amplified and detected using phase-sensitive techniques. The audio goes into an audio "lock-in" detector whose reference signal is derived from the same source as the field modulation.
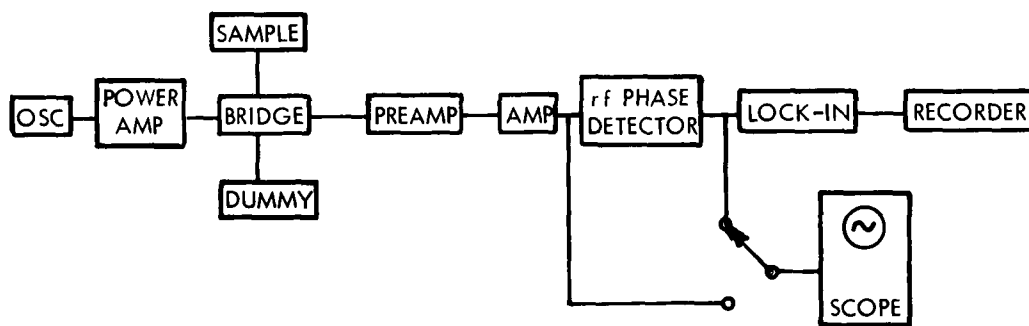
FIGURE 8. Block diagram of bridge spectrometer.

Program for the next interval: Double nuclear magnetic resonance experiments will soon be performed on Li^7 nuclei in LiCl.

C. ADIABATIC DEMAGNETIZATION IN THE ROTATING FRAME*
(S. Hartmann)

Work on the new program for the study of the demagnetized state, which was discussed in the last Quarterly Report, has begun. Delivery of the large 12-inch magnet required for this work is not expected until February, and in the meantime electronic apparatus is being built for use in this program. A small 6-inch magnet has been obtained for preliminary measurements with a spin echo apparatus recently built for the measurement of spin-spin and spin lattice relaxation rates. The major items of electronic equipment now under construction are a high power rf transmitter and receiver for performing ADRF and a cw system which consists of an rf bridge and detector.

Calculations are being made to give the spin lattice relaxation rate of solid He^3 as a function of temperature and magnetic field[1,2] at values of the magnetic field of the order of 500 G. This is mentioned here since one of the mechanisms that gives rise to the relaxation of the He^3 nuclei is the spin-spin coupling between the Zeeman and the exchange systems (or stated in another way, between the magnetized and the demagnetized states). A preliminary result has been obtained[2] which gives the relaxation rate W as proportional to

$$W \propto \frac{1}{\omega_e} \left\{ w(iz) + w(iz^*) \right\}$$

where

ω_e = a measure of the exchange field,

$z = \dfrac{1 + i\omega \tau}{2\omega_e \tau}$

$\omega = \gamma H$,

γ = gyromagnetic ratio of He nuclei,

$$H = \text{applied dc magnetic field,}$$

$$\tau = \text{correlation time associated with the diffusion of the } He^3 \text{ nuclei,}$$

and
$$w(z) = \exp(-z^2)\left\{1 + \frac{2i}{\sqrt{\pi}} \int_0^z \exp(t^2)\, dt\right\}\ .$$

The relaxation rate reduces to the form

$$W \quad \frac{1}{\omega_e} \sqrt{\frac{\pi}{4}} \exp\ -\frac{\omega^2}{4\omega_e^2}$$

when
$$\tau \longrightarrow \infty$$

and
$$W \propto \frac{\tau}{1 + \omega^2 \tau^2}$$

for $\omega_e \ll \omega$, $\omega\tau \gg 1$. In these two limits we have the standard expression for ω due to the coupling between the Zeeman and exchange systems[3] and due to diffusion alone.[4] The above equations are in good agreement with experiment.

At the present time calculations are being made to determine ω_e for He^3 and to obtain expressions for W in which we treat the diffusion and spin-spin coupling processes as independent.

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(1) Goodkind and Fairbank, Phys. Rev. Letters 4, 458 (1960).

(2) H. Reich, to be published.

(3) Kronig and Boukamp, Physica 5, 521 (1938).

(4) Bloembergen, Purcell, and Pound, Phys. Rev. 73, 679 (1948).

V. OPTICAL AND MICROWAVE MASERS

A. INFRARED AND OPTICAL MASERS

1. Optical Maser Spectroscopy*
(H. Z. Cummins, N. Knable, L. Gampel, Y. Yeh)

In our last report[1] we discussed a new type of spectroscopy in which optical maser heterodyning techniques are used to measure frequency shifts produced by light scattering in liquid or solid media. We have, in the intervening period, completed two series of experimental investigations preliminary to the central experiment which is now in the final stages of construction. These were: a) A determination of the sensitivity and stability of the optical heterodyning process, and b) a series of measurements of the light-scattering process in an electrically driven water cell.

a) Optical Heterodyning Measurements

1) A 6328 $\overset{\circ}{A}$ He-Ne maser with a 7 ft, 6 in. central tube terminated in Brewster angle windows and with spherical mirrors of 6 ft, 3 in. radius separated by 8 ft, 10 in. was initially operated with its output beam (after filtering and attenuation) directed onto the photocathode of an EMI 9558B photomultiplier. The photomultiplier output signal was processed with a Polarad TSA-W spectrum analyzer which in turn was calibrated with a Hewlett-Packard 608D signal generator. We were able to measure the beat signal power as a function of operating conditions in the maser. Optimum signal power (at the fundamental difference frequency for successive axial modes $\Delta v_o = 60$ Mc) was found to be -32 dBm with a dc photomultiplier output of 450 μA.

If we assume that the maser output consists of two equal intensity modes only, the anticipated beat signal current would be 3×10^{-4} A, or about three times larger than the observed signal. Simultaneous operation in a larger number of modes or unequal amplitudes of the different modes would lead to a reduction in anticipated signal. Therefore, we conclude that the heterodyning efficiency (in the case of intermode beats) is at least 30%.

The large efficiency in this case results from two highly favorable circumstances: (i) The frequency instability resulting from mechanical fluctuations in the maser structure occurs simultaneously in each axial mode so that the difference frequency is (to first order) constant; (ii) the different components in the output beam traverse the same optical path so that thermal and mechanical fluctuations in the collecting and mixing optics affect all components in the same way.

2) The remaining heterodyning experiments were performed with the apparatus shown in Fig. 9. Both the maser beam and the collimated output of an Osram mercury lamp entered the Mach-Zender interferometer (I)
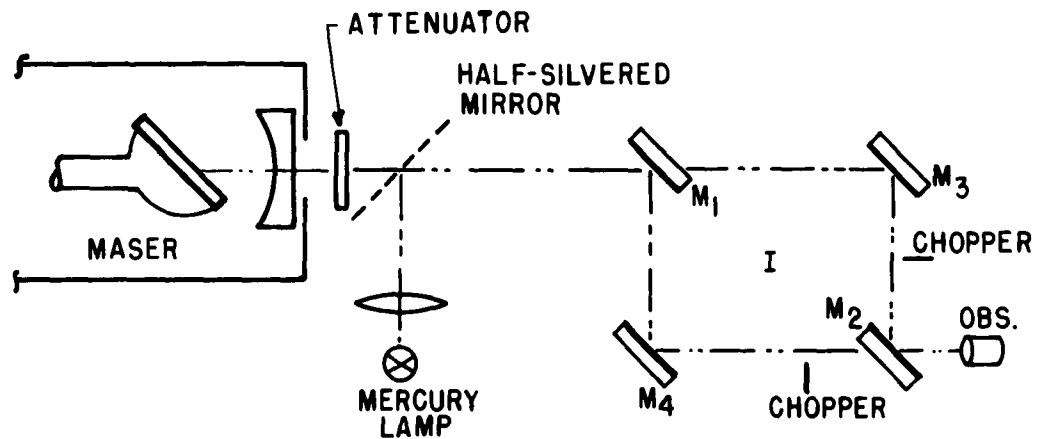

FIGURE 9. Heterodyning apparatus.

which was constructed of steel I -beams and which measured approximately 12 in. on each side. Initially a telescope was placed at the output position (OBS) and the mirrors M_1 - M_4 were adjusted to produce mercury white light fringes. With the telescope focused at infinity, the mirror alignment

was adjusted until the green fringe spacing was at least 10 times the apparent size of the maser red spot. Thus parallelism of the recombined maser beams was accurate to better than $\lambda/10$.

At this point the telescope at OBS was replaced with a photomultiplier, and the signals produced by each beam separately and by both beams together were measured. We found that the current produced by the two beams together could be made to vary (within the limits of observation) between $(\sqrt{I_1}+\sqrt{I_2})^2$ and $(\sqrt{I_1}-\sqrt{I_2})^2$ [where I_1 and I_2 are the currents produced by the individual beams] by slight adjustment of the interferometer, indicating perfect efficiency for the homodyning or zero beat process. Slow drifts between the extremes were observed with an average period of about 1 cps. Thus in the final experiment where one beam will have an imposed frequency shift before recombination, a resultant broadening of the beat spectrum of several cycles per second is to be expected.

3) A series of measurements[2] was carried out with the apparatus of Fig. 9, with two incoherent sources in the arms $M_1 - M_4$ and $M_1 - M_3$ replacing the maser. In this case beat signals are produced only through nonlinearities in the photomultiplier. With the EMI 9558B that was employed, a nonlinearity of between 4% and 0.05% was found for photocathode currents ranging from 2×10^{-1} to 2×10^{-4} µA. This result is of importance in the optical maser spectroscopy work since nonlinearity in the detector will produce spurious beat signals at integral multiples of fundamental frequency shifts.

b) Light Scattering in a Driven Water Cell

Measurements of light scattering from a water cell driven by a quartz transducer, which we discussed in our last report,[1] were extended. G. W. Willard[3] had observed in 1949 that, for a sufficiently large crystal, Bragg reflections occur (for particular tank orientations) concurrently with the Debye-Sears diffraction effect. We have installed a large (40 mm) quartz transducer with a 5 Mc fundamental in our water tank and have made extensive measurements of scattering at various angles as a function of tank orientation with excitation frequencies of 5, 15, and 25 Mc. At 5 Mc the scattering is pure Debye-Sears, while at 25 Mc, it is nearly pure Bragg, with the 15 Mc case exhibiting both effects. It was necessary to collect a large amount of intensity data in order to have a reasonable basis for interpreting the frequency shift data which we expect to obtain.

FIGURE 10. Schematic diagram of experimental apparatus.

Program for the next interval: Fig. 10 shows the optical maser spectrometer which is now nearly completed. The He-Ne maser has been rebuilt within a massive invar housing to provide maximum stability. The maser beam splits at the half-silvered mirror M_3. Part of it (optical local oscillator) goes to photomultiplier 2 directly via mirrors M_9 and M_7, while the rest traverses the water tank before recombining with the local oscillator beam at M_7. The output of photomultiplier 2 will first be processed with the spectrum analyzer (which is mechanically swept) and then by the lock-in amplifier which is phase locked to the chopper in the signal beam. Frequency spectra of the various orders may be obtained by positioning the slit appropriately.

The results discussed above will then permit us to interpret the spectra obtained. Although considerable difficulty is anticipated in achieving optical alignment, it is expected that some spectra will be measured during the coming period.

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(1) CRL Quarterly Report, Sept. 15, 1962, p. 40.

(2) To be published.

(3) G. W. Willard, J. Acoust. Soc. Am. 21, 101 (1949).

2. Ruby Maser*
   (I. D. Abella)

In the previous report we described some results of the experiment on double-quantum absorption in cesium vapor, using a pulsed ruby laser source.[1,2] These results can be summarized as follows: The light from the ruby source (14 400 cm^{-1}) was focused onto a heated cesium cell. The $9D_{5/2, 3/2}$ levels in atomic cesium are at 28 836 and 28 828 cm^{-1} above ground and hence can be excited by the absorption of 2 quanta from the laser beam since the energy and parity of these states are correct for a two-electric-dipole process.

The absorption was detected with a narrow band interference filter and a photomultiplier by observing the decay of the excited state in the $9D_{3/2} - 6P_{3/2}$ transition at 5847 Å. Calculations based on Bates and Damgaard showed that, for the characteristics of our laser beam and assuming purely radiative processes, about 5×10^{11} photons would be produced in the 5847 Å line. However, the number of photons detected at the photocathode was about 4×10^4, and allowing for geometry and $CuSO_4$ filter absorption, the total number emitted in the cell was 5×10^9 or some factor of 10^2 below the number expected.

In the preceding report we considered as a possible explanation for the loss of signal the quenching of the $9D_{3/2}$ state due to cesium-cesium collisions. We have calculated an approximation to the quenching rate on the basis that it occurs whenever the electric dipole-dipole interaction $(\Delta E \approx \mu_1 \mu_2 / r^3)$ is as great as the energy separating atomic levels, where r is the effective collision radius. For the $10P_{3/2}$ state $(\Delta E \approx 75 \text{ cm}^{-1})$ the predicted collision time is some 100 times faster than the radiative lifetime of the $9D_{3/2}$ state, which is the discrepancy observed. One could test this quenching theory by observing the presence of other spectral lines and measuring their dependence on vapor pressure.

Program for the next interval: Work is in progress on the building of a "pulsed reflector" ruby laser to obtain high powered pulses of brief duration.[3] A Kerr electroptic shutter is employed to spoil the "Q" of the cavity during the optical pump cycle, thus permitting a higher degree of population inversion. The Kerr cell and power supply are being tested, and further work employing this device will be described in the next report.

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(1) I. D. Abella and C. H. Townes, Bull. Am. Phys. Soc. 7, 554 (1962).

(2) I. D. Abella, Phys. Rev. Letters 9, 453 (1962).

(3) F. J. McClung and R. W. Hellwarth, Bull. Am. Phys. Soc. 6, 414 (1961).

B. SENSITIVITY OF MICROWAVE SPECTROMETERS USING MASER TECHNIQUES*
(H. Lecar)

The experimental work on the maser paramagnetic resonance spectrometer has been completed. The purpose of this experiment was to test a proposal by Townes[1] that the ultimate sensitivity of microwave spectrometers could be increased by coupling a maser directly to the spectrometer cavity and observing the effect of the resonant absorption on the maser output. The theory of the effect, the design of the spectrometer, and a qualitative account of its operation have been given in earlier reports.

During the past quarter further consideration has been given to the practical application of a regenerative maser spectrometer to high sensitivity paramagnetic resonance experiments. It was found, when saturation effects were studied in detail, that the maser spectrometer was capable of attaining very high sensitivity at low input power levels, but was incapable of improving the theoretical ultimate sensitivity of a spectrometer operating at the optimum power level.[2] The situation is somewhat analogous to that of the autodyne and marginal oscillator schemes in radio-frequency magnetic resonance work.

It was also found that certain sources of noise, other than thermal fluctuations in the cavity radiation field, which are not of great importance for conventional microwave spectrometers are of crucial importance in the operation of the regenerative maser spectrometer.

Two such sources of noise, which have been studied in detail, are: frequency instabilities in the source oscillator, and gain fluctuations in the maser. Frequency-instability noise is more critical here than for conventional spectrometers because the maser has such a narrow bandwidth when it is operating at the high gains needed to make use of the regenerative effects. Conventional stabilized microwave oscillators with frequency output stable to 5 parts in 10^8 were used in this experiment. These introduced more noise than the thermal noise sources in the cavity. However this source of noise can be overcome by using harmonics of stable low frequency oscillators, since the regenerative spectrometer needs input power of the order of only 1 microwatt.

Noise caused by gain fluctuations, on the other hand, proved to be the real limiting factor for this technique. The very sensitivity to small changes in susceptibility that makes a regenerative device of this sort useful also makes it extremely sensitive to gain changes introduced by extraneous sources. This source of noise is being analyzed in more detail at present.

Program for the next interval: During the next quarter the analysis of the maser paramagnetic resonance spectrometer will be completed. The final results will be given in a later Quarterly Report.

---

(1) C. H. Townes, Phys. Rev. Letters 5, 428 (1960).

(2) H. Lecar and A. Okaya, Procedings of the First International Conference on Paramagnetic Resonance, Hebrew University, Jerusalem, Israel, August 15, 1962 (to be published).

C. RUBIDIUM MASER
(P. Davidovits, N. Knable)

During the last quarter experiments were conducted to determine the gain and bandwidth of the rubidium maser using a cavity constructed for the TE_{011} mode. The cavity contained a glass cell filled with Rb^{87} and 6 cm of nitrogen. The data were obtained as a function of temperature and are shown in Fig. 11 and 12.

Before discussing the results it should be pointed out that the gain measurements for temperatures greater than 70°C were unreliable because at these temperatures the cell became coated with rubidium, reducing the system Q. To correct this situation we have made a glass cell with a temperature controlled Rb reservoir, the oven being held at a higher temperature. Experiments with such a cell are now in progress.
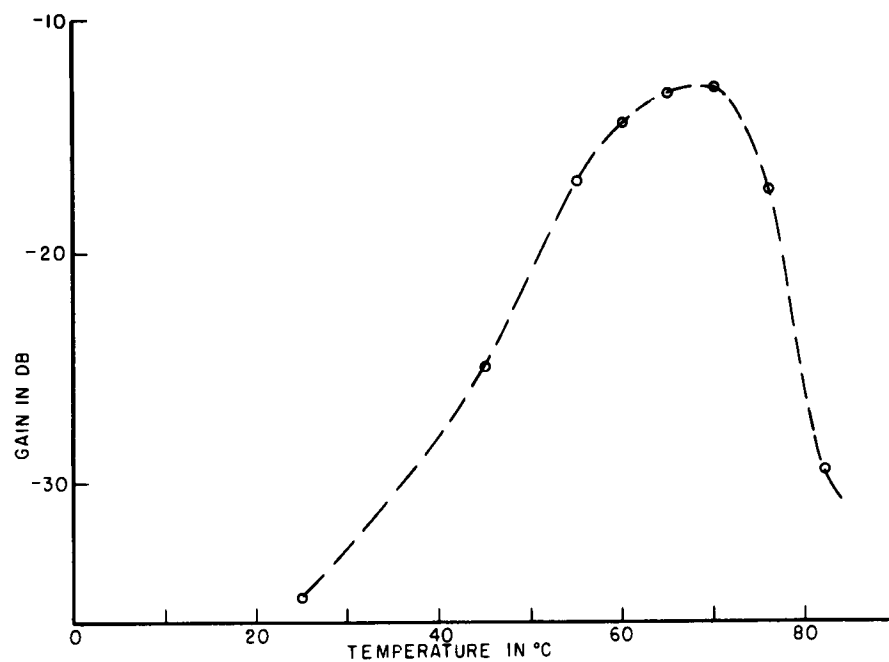
FIGURE 11. Gain vs temperature.
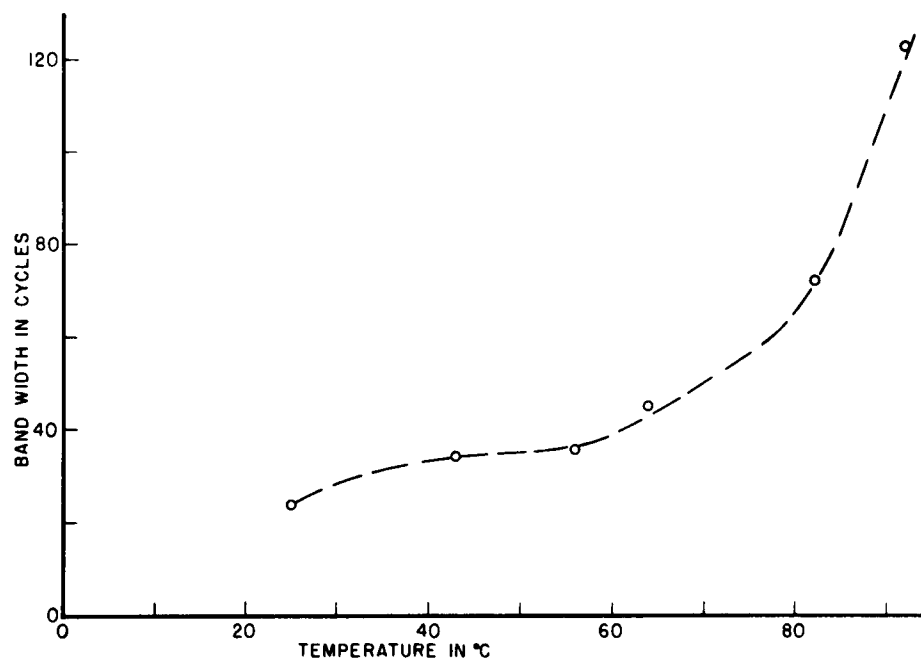
FIGURE 12. Bandwidth vs temperature.

The power gain of the matched maser is:[1]

$$G = \frac{L^2}{(1-L)^2} \tag{1}$$

where

$$L = \frac{2 k_1 Q_o}{k_o \, \nu \, V \left[(\nu - \nu_o)^2 + \left(\frac{1}{2 \tau T_3} \right) \right]^2} \quad ,$$

Q_o = quality factor of the cavity,

V = volume of the cavity,

k_o = filling factor,

$k_1 = \frac{(N_+ - N_-) \, h \, \nu}{2 \, T_3} \left(\frac{|\mu|}{h} \right)^2$

N_+ = number of atoms in $F = 2$, $m_F = 0$ state,

N_- = number of atoms in $F = 1$, $m_F = 0$ state,

and T_3 = total relaxation time of Rb^{87} in $F = 2$, $m_F = 0$ state.

Using the above equations we calculated T_3 from the measured bandwidths. Assuming that T_3 is given by

$$\frac{1}{T_3^2} = 2 \, n^2 \, \bar{v}^{-2} \, \sigma^2 + \frac{1}{T_D^2} \tag{2}$$

where

n = density of rubidium atoms,

$\bar{v}$ = rms velocity of rubidium atoms,

σ = spin-spin relaxation cross section for rubidium atoms,

T_D = mean free time between disorienting collisions from sources other than rubidium-rubidium interactions,

and if T_D is independent of temperature, we can then plot $\frac{1}{T_3^2}$ vs $2 \, n^2 \, \bar{v}^{-2}$,

where $\overline{v}^2 = \dfrac{8kt}{\pi m}$ (Jeans) ,

and n^2 is assumed to be that given in the data of Hornig.[2] The slope of this curve (Fig. 13) is σ^2. Thus,

$$\sigma^2 \simeq 0.715 \times 10^{-28} \, cm^4 \,,$$
$$\sigma \simeq 84.5 \times 10^{-16} \, cm^2 \,.$$

Note that these numbers should not be considered accurate as the uncertainty in the Rb density is great. It is gratifying that the temperature dependence is correctly predicted. A true cross section will depend on optical density measurements.

In an uncoupled cavity the power emitted by the molecules at ν_o is given by

$$P_e = \frac{H^2 L \, k_o \, \nu_o \, V}{2 \, Q_o} \,.$$

The power lost is given by

$$P_\ell = \frac{H^2 \, k_o \, \nu \, V}{4 \, Q_o} \,.$$

The threshhold of oscillation is reached when

$$P_\ell = P_e \,,$$

or

$$L(\nu_o) = 1/2 \,.$$

It can be seen that with the present system an L of 0.18 has been obtained. Thus an increase in Q_o by a factor of 2.8 will bring about oscillation.

In order to achieve higher Q we have experimented with glass and quartz cells for a cavity using the TE_{021} mode. Unfortunately those cells which were thin enough not to perturb the dominant mode imploded when evacuated, and the cells with sufficient wall thickness lowered the Q of the system to a value below that of the TE_{011} system. For this reason work along this line has been stopped.
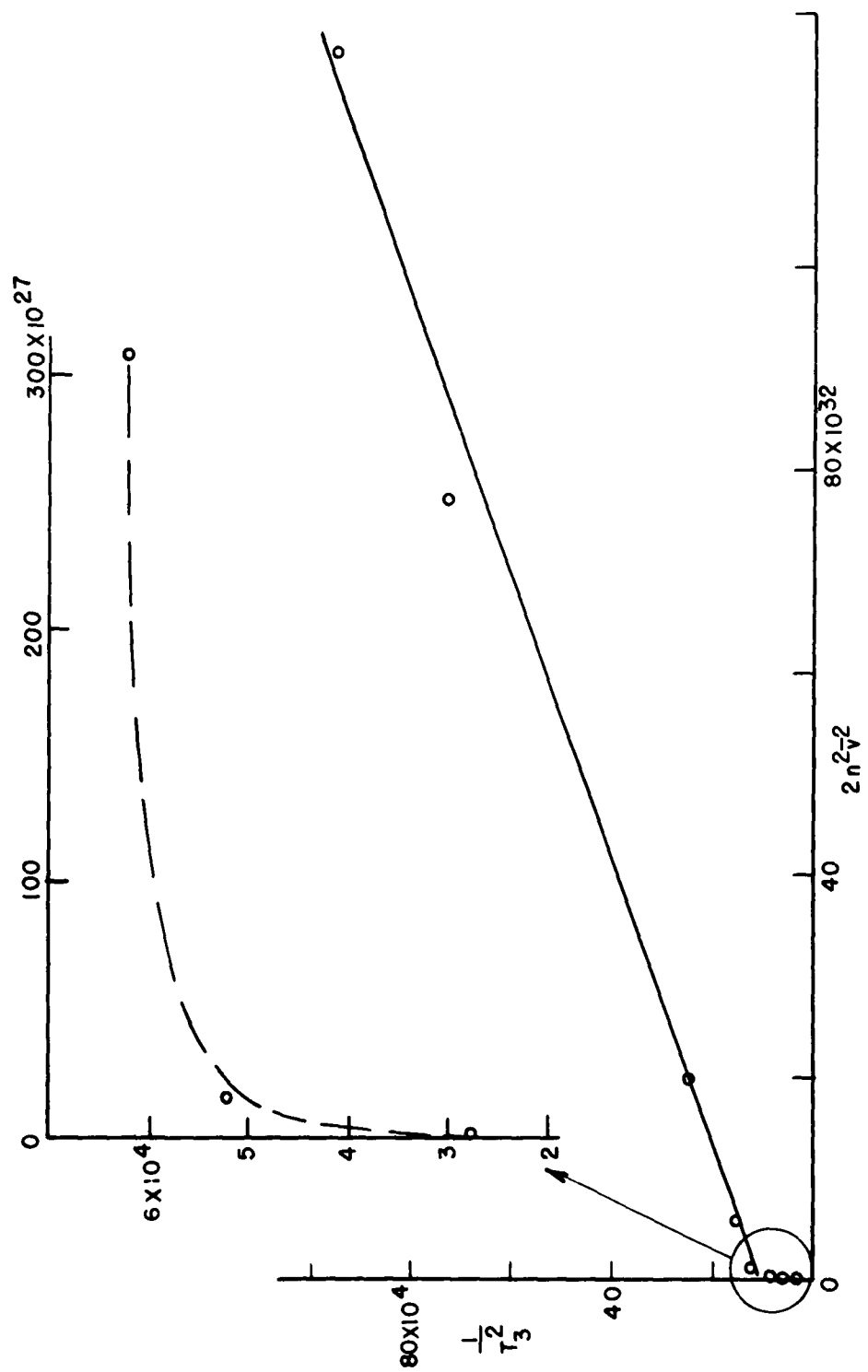
FIGURE 13. $1/T_3^2$ vs $2n^2 \bar{v}^2$

We are now building a vacuum tight cavity. To this end we have tested the reaction of a number of materials with rubidium. Oxygen-free copper, stainless steel, and copper-plated stainless steel show no apparent reaction with rubidium at 250°C. A copper-plated stainless steel cavity which will use glass and copper "O" rings for admitting the pumping light is now under construction.

Program for the next interval: During the next quarter we plan to complete the experiments on the TE_{011} cavity using the new type of cell and to continue working on the vacuum tight cavity.

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(1) James P. Wittke, "Molecular amplification and generation of microwaves," Proc. Inst. Radio Engrs. 45, 291 (1957).

(2) R. E. Hornig, "RCA vapor pressure charts for common metals."

VI. RADIOASTRONOMY

A. THE 10-CENTIMETER MASER FOR RADIOASTRONOMY
(W. K. Rose)

From observations made during August-October, 1962 using the 9.4 cm maser mounted at the focus of the Naval Research Laboratory 84-foot radio telescope, we determined that the 3200 Mc/sec radiation from Saturn is linearly polarized. The measurements provide a lower limit of $20 \pm 8\%$ for the degree of polarization, and the maximum intensity occurs with the electric field vector oriented almost parallel to the axis of rotation.

If we assume that the radiation is due to relativistic electrons radiating in the magnetic field of Saturn, our results imply that the magnetic poles are close to the equatorial plane. There are at least two difficulties with this interpretation. If the thermal radiation is subtracted from the observed equivalent blackbody disk temperatures, the degree of linear polarization associated with the nonthermal component is increased to about 50%. Some explanation needs to be introduced to account for the flat helix electrons required for this very high polarization. Another difficulty is created by the rings which presumably act as a damping mechanism for the relativistic electrons.

One way of avoiding these objections is to postulate that the rings damp out those electrons that would otherwise form an inner Van Allen belt and that the electrons which are beyond the rings have flat helices and hence emit very polarized radiation. This interpretation of Saturn's 3200 Mc/sec radiation is consistent with observations of Jupiter which show that its 31 cm radiation is most intensely polarized at distances of the order of 3 radii from its axis of rotation.

B. M-BAND RADIOTELESCOPE *
(W. Kahan)

A search was made during the months of September and October to find the intensity variation of the telluric ν_{27}- O_2 line. Although small variations of the order of 10% were observed, we did not see any variations

comparable to those found in the fall of 1961.[1] At the end of October the radiotelescope was shut down for the winter because during this period the sun is too low in the sky to afford sufficient running time.

Calculations have been made to determine the maximum solar abundance of nitrogen consistent with the absence of an observed coronal emission line stemming from the hyperfine transition in the ground state of sextuply ionized nitrogen. Detailed computations of ionization and recombination rates in the coronal plasma were necessary to determine the ratio of the number of N VII atoms to the total number of nitrogen atoms. A machine calculation was also made on NASA's 7090 computer to arrive at the number of coronal atoms per unit area along a line of sight as a function of the angular distance of the line of sight from the sun's center. By combining the results of the calculation with theoretical expressions for the formation of microwave emission lines, we learned that a radiotelescope with output fluctuations corresponding to 5°K could not detect the N VII hfs line which passes through the earth's atmosphere unless there were at least 8×10^{10} nitrogen atoms per cubic centimeter at the base of the solar corona.

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(1) W. Kahan, Nature 195, 30 (1962).

C. MODELS OF PLANETARY ATMOSPHERES*
(W. Ho, R. Osborn, P. Thaddeus†)

The V 40-B klystron tube previously used as the power source in the cavity-resonance type microwave spectrometer failed due to a defect in its construction, and it was not possible to take data until the arrival of a new tube. Therefore, the past quarter was devoted to perfecting the frequency-locking system and to improving the sensitivity of the spectrometer. It is now possible to stabilize the klystron frequency to within

1 kc of the desired frequency for short durations, or better than 5 parts in 10^8. The system can now measure the gas absorption constant a to better than 10^{-7} cm^{-1}. Measurements on the absorption of microwaves by various gases will be made immediately upon arrival of the new klystron tube.

Calculations have been carried out on the theoretical variation of Q values of the tunable cavity used as a function of cavity dimension. The result of the calculations will be compared with the experimental value.

Program for the next interval: Quantitative measurements will be made on the absorption of microwaves by CO_2 at various pressures and by mixtures of CO_2 and other dipolar gases.

VII. CRYOGENICS

A. HIGH FREQUENCY PROPERTIES OF SUPERCONDUCTORS*
(S. Zemon)

During the first half of the last quarter this research was temporarily halted. We devoted the rest of the quarter to preparations for taking more data on the surface resistance of the same zinc cavity as in the past, using improved techniques. The major improvement planned will be the installation of a specially constructed 3 dB directional coupler which is lightweight and shaped so that it can conveniently fit into the cryostat. Thus the directional coupler will be quite close to the cavity with no major source of spurious reflection which might cause some of the incident power to be reflected into the detector arm as it did in the last run. The VSWR of the straight-section arm of the directional coupler has been measured at selected frequencies between 50 and 75 kMc and found to be about 1.1, so that we may expect a spurious signal of about 1% of the reflected power (the rated directivity is greater than 20 dB).

This improvement in the microwave arrangement may interfere with the attainment of the lowest temperature region. Only about 4 in. of 10 mil wall brass waveguide (with dimensions 0.074 in. x 0.148 in.) will separate the cavity from He^4 temperatures. It remains to be seen whether this length is sufficient for good thermal isolation.

An attempt will be made to use bolometers instead of crystals as microwave detectors. Initial trials have shown an order of magnitude increase in sensitivity with the bolometers which will be particularly useful at the higher frequencies (75 - 82 kMc).

An improvement in the temperature measuring technique has resulted from the acquisition of a Leeds and Northrup AZAR recorder. It has an adjustable zero and adjustable amplification as well as a marker pen. Thus the measurement of the resistance value of the secondary thermometer when the frequency goes through the resonant frequency will be facilitated.

High voltage mylar (2000 volts) condensers which have low leakage will be purchased to replace the ordinary quality ones now in use in the klystron power supply in an effort to improve the stability.

Finally, plans have been drawn up for two low loss, 24 hr, liquid nitrogen traps so that filling will be less of a problem.

Program for the next interval: Data will be taken on the zinc cavity using improved techniques.

B. RADIATION PRESSURE OF SECOND SOUND IN LIQUID HELIUM II
   (C. Metz)

During the last quarter measurements of the radiation pressure of second sound in liquid helium II were concluded, and the thesis outline was written.

Program for the next interval: Calculations will be finished, and the thesis will be written.

C. ELECTRONIC AND LATTICE HEAT CAPACITIES OF SUPER-
   CONDUCTORS
   (H. Leupold)

During the last quarter the specific heat measurements on the niobium crystal mentioned in previous reports were extended down to approximately 0.85°K. The precision of these measurements is very much better than any heretofore obtained, and it is now certain that the anomaly observed in the polycrystal also exists in the single crystal and is of the same magnitude down to approximately 1.1°K. Below 1.1°K the anomaly in the single crystal seems to be smaller and may even disappear below about 0.95°K.

Program for the next interval: Modifications in the equipment are now being made to make possible new measurements down to 0.4°K which will throw further light on the form of the anomaly.

VIII. MAGNETRONS AND SPECIAL DEVICES

A. UNIVERSAL RESONANCE LAMP*
(R. J. Goshen, A. Lurio,† R. de Zafra)

A paper is being prepared for the Review of Scientific Instruments which will contain the design and some results of tests with the flow lamp. Up to the present we have used the lamp to excite transitions in the following elements: Cd, Zn, Ca, Ba, Sr, Hg, Li, Na, and Tl. An intensity comparison of the flow lamp and the hollow cathode lamp has been made in the case of the lithium resonance lines.

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†IBM Watson Laboratory.

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